The River Nile

Geology, Hydrology and Utilization

Rushdi Said
former head of the Geological Survey of Egypt

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THE RIVER NILE

Geology, Hydrology and Utilization

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on the occasion of his sixtieth birthday

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CONTENTS

PREFACE

This book is the result of many years of research. It is an attempt to reconstruct the history of the river Nile from its origins to its present shape and regimen. It is also an attempt to ascertain the amount of water which was carried by the river during the course of its history, the manner in which this water was utilized in the past and the manner in which it has to be utilized in the future if the inhabitants of the river basin are to cope with their increased needs.

Although this book has for its subject the entire Nile Valley, the reader will find that the Egyptian part of the Nile has been treated at greater length. There are many reasons for this emphasis. In the first place, the Egyptian Nile is one of the best known parts of the river; it has been the subject of numerous studies by multidisciplinary groups during the past three decades. It has also been penetrated by a large number of boreholes some of which have reached the oldest of its sediments offering an almost complete and uninterrupted record of its history. Furthermore, the Nile in Egypt lies in the downstream part of the river whose regimen and sediments are affected by events in the upstream part and can tell us, therefore, a great deal about changes and developments occurring there.

There is a fascination about the Nile which has captured people's imagination throughout history. Nowhere has this fascination been greater and longer lasting than with the Egyptian end of the river. Here emerged a great civilization some five thousand years ago which depended entirely on the river and its annual inundation. Yet the secret of this inundation and the sources of this great river remained a mystery for this literate, vigorous and highly organized society. For a very long time after the demise of this civilization the question of the sources of the Nile stirred the imagination of men; it became of cardinal concern to the world at large during the nineteenth century when explorers finally resolved the mystery.

The Nile's beginnings, when it first appeared, and how it assumed its present shape and regimen were other enigmatic and baffling questions which occupied the minds of men from the earliest of times. Like the sources of the Nile, the beginnings of the river were also wrapped in mystery and became the subject of legend. For most of the twentieth century the facts about the early history of the river were unknown and, in the absence of these, even the scientists' attempts to reconstruct the early history of the river were no more than speculations that bordered on legend. The real breakthrough in this field occurred when the river's earliest sediments became amenable to study. These sediments are deeply buried under the surface, and were reached only lately by many of the deep boreholes drilled in the delta of the Nile by companies exploring for oil. My consulting work exposed me to the wealth of data from these boreholes which held the secrets of the river. Not only did these boreholes reach the oldest sediments of the river but they also preserved a complete record of them. The task of

reconstructing and interpreting the column of sediments of the river was facilitated and greatly enhanced by another breakthrough resulting from the publication of a study of boreholes drilled off the coast of the Nile delta in 1972 by the Deep Sea Drilling Project, an international effort to study the bottom of the oceans. By correlating the delta boreholes with those of the Deep Sea Drilling Project we were able to unfold the early history of the river and to show its tumultuous evolution and tenuous connections with sub-Saharan Africa.

The later history of the river has been closely associated with man. Many questions awaited an answer such as when man first appeared along the banks of the river and where did he come from? Did the moods of the river influence his settlement patterns, and who were the men who were responsible for that spectacular civilization that appeared on the banks of the lower parts of the river some five thousand years ago? Little was known about the earlier settlers of the valley until lately, for inspite of the fact that excellent studies had been made on some of their sites since the beginning of the twentieth century, these studies were few and scattered. The real breakthrough took place in the 1960's when systematic studies in the field of prehistory were conducted along the banks of the Nile, as part of the international campaign launched to save the monuments of Nubia which were about to drown beneath the waters of Lake Nasser, that was forming as a result of the building of the Aswan High Dam. It was my good fortune to be associated with this program of research conducted by an interdisciplinary team made up of a core of archeologists. Although much remains to be done in this field, we now have at least a credible concept of the history of the early settlement of the valley.

In addition to the chapters dealing with the historical aspects of the river, this book also includes chapters which treat the present and future state of the river and the utilization of its waters. The patterns of water utilization are determined by the amount of water carried by the river, which fluctuates from year to year. For those of us who started their interest in the Nile from a historic, if not a prehistoric, perspective, the present-day unprecedented small flows of the river, caused by the drought that has been ravaging the Sahel region for the past two decades, seem to be part of a natural phenomenon and seem likely to continue. The low rainfall in the Sahel and the Ethiopian Highlands of recent years is further evidence of the phenomenon, which we have documented during our studies in prehistory, whereby sequences of low Nile flows and sequences of high Nile flows tend to follow each other. My concern about the impact of these anticipated low flows on the rising demands of the inhabitants of the river is heightened by my readings on the geological history of the river, which seem to point to an even less benevolent Nile in the long run.

This book, therefore, is of interdisciplinary nature. It deals with many aspects of the Nile. It is made up of four parts, and an appendix listing the references used and some of the pertinent literature on the river. Because users of this book will have different backgrounds an effort has been made, where possible, to present the scientific material included avoiding the use of technical terms. Part I deals with the origin and evolution of the river. The story of the development of the river until it assumed its present shape is truly fascinating. The subject matter of this part is technical and I have tried to present it as simply as possible. However, for the benefit of those readers who would find difficulty in following this account, a summary outlining the story of the river in non-technical language is offered at the beginning of this part.

Part II deals with the hydrology of the river and the amount of water that the river and its tributaries carry at present. It also attempts to ascertain the amount of water that the modern river

carried in the past from the time of its inception some 10,000 years ago. At that time great climatic changes were taking place in the Nile Basin and wetter conditions prevailed over most of the basin causing the river to carry greater amounts of water than today. These amounts declined with the steady southward retreat of the rain front some 5000 years ago, leaving large areas of the basin arid. Within that general trend, the flow of the river has fluctuated greatly throughout its history.

Part III deals with the utilization of the waters of the Nile from the time of the first appearance of man in the valley until the present time. It traces man's attempts to harness the river from the earliest times to the time of the building of the High Dam at Aswan, which resulted in the full control of the river and the conversion of its lower course into a man-made canal. After twenty years of the operation of the dam, an attempt is made to evaluate its side effects.

Part IV deals with the present water supply–demand balance in each basin state and discusses the future plans of these countries to use the waters of the Nile. Historically and until recently Egypt was the sole user of the waters of the river. Rapidly growing populations and the frequent and prolonged droughts of recent years are forcing many of the basin states to abandon rain agriculture in favor of irrigated agriculture, and are thus demanding a share of the waters of the river. This causes problems to all basin states not only with regard to the legal aspects of the division of the waters of the river, but also with regard to the urgency of adopting efficient methods for the use of the limited water resource. This part examines the status of the present Nile Water Agreements among the basin states and shows that they fail to address the present-day needs of these states.

With the exception of some conclusions and speculations, many of the facts bearing on the wide variety of subjects dealt with in this book are extracted from works listed in the appendix. The sections of the book which deal with topics outside my speciality were written after discussions with specialists who kindly read my notes or added to my knowledge of the subject. I owe them a word of thanks. Professor Klaus Fraedrich, Professor of Meteorology, Free University of Berlin, read section eight (Part I) dealing with the climate. Engineer Naguib F. Said, former under secretary of State, Egyptian Ministry of Irrigation, read the sections on the irrigation works in Egypt and the Sudan. Professor John Waterbury, School of Public and International Affairs, Princeton University kindly found time to read parts one and two of the book. I owe my rudimentary knowledge of prehistory to Professor Fred Wendorf, Southern Methodist University, who led the Combined Prehistoric Expedition in Egypt when it worked closely with the Geological Survey of Egypt which I headed until 1978. I also owe a word of thanks to Professor D. Wildung and Dr Karla Kroeper, Berlin Egyptological Museum for allowing me the free use of their excellent library and for drawing my attention to pertinent literature. Dr Kroeper corrected the locations and spelling of some of the ancient sites which appear on the map of the delta (Fig. 1.30). Thanks are also owed to Professor M. Kassas, Cairo University, for supplying me with material regarding the quality of the water of the Nile; to Dr A. el-Gazzar, agricultural attache of the Egyptian Embassy, Washington for the agricultural statistics included in the book; to Engineer Abdel Hadi Radi, under secretary of state for the Egyptian Ministry of Irrigation, for fruitful discussions and for making available to me the *Journal of Water Science* which he edits and which includes useful summaries of the work carried out by the different research institutes of the Ministry; and to Dr Abdel-Aziz Sadek, head of the Documentation Center, Egyptian Antiquities Authority, for supplying me with practically

all the photographs of ancient Egypt (Figs 2.13, 2.14, 2.18, 2.21, 3.9, 3.11, 3.12, 3.20 and 3.21). Thanks are also due to Amoco Egypt for defraying part of the cost of the drafting of the figures of the book.

I owe a special word of thanks to my wife Wadad not only for enduring the inconveniences incidental to the writing of this book but also for reading the many versions of its manuscript.

This book could not have been written had I not been invited to spend the academic year 1989/90 as a fellow at the Institute for Advanced Study in Berlin (Wissenschaftskolleg). This year allowed me to free myself from my busy schedule and to devote my entire time to organizing field notes and information which I had amassed over the years on the River Nile and synthesizing them into a whole. I owe a special word of gratitude to Professor Wolf Lepenies, the dean of the Institute, for his gracious hospitality and for the genial and research-conducive atmosphere of the Institute, which allowed me to finish this work. I also owe a debt to Professor E. Klitzsch, Technical University of Berlin, for his continuous support. To him this book is dedicated.

Washington, D.C.,
October 1992.

PART I

ORIGIN AND EVOLUTION OF THE RIVER NILE

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SUMMARY OF PART I

Part I deals with the geological history of the Nile river from the time it started to excavate its valley some six million years ago. This summary is intended for the general reader and is written in non technical language. The history of the river as outlined in this summary is given without going into details or discussing the nature of the evidence from which this history has been construed. The reader must recognize that geologic events which shape the features of the earth such as the tilting of mountains, the formation of rift valleys, the advance and retreat of ice and the rise and fall of sea level do not happen abruptly but take place over thousands if not millions of years. The reader must also remember that with the exception of the recent dates (40,000 years and younger) all other dates are very approximate and relative. The older dates are estimates based on the position of the event relative to another event which is better dated.

The shape of the Nile we know today is a very recent development; it is but the last stage of a continuously evolving river which changed its face many times before it assumed its present look. The present-day river is complex, and is the result of the interconnection of several independent basins by rivers which developed during the last wet period which affected Africa after the retreat of the ice of the last glacial age some 10,000 years ago; the modern Nile is indeed the child of that wet phase. Prior to this, the basins which constitute part of the present river were disconnected, forming internal lakes. At times when the climate was wet they overflowed their banks and became connected to other basins; at other times when the climate was dry they ebbed, shrank into saline pools or dried altogether. Figures 1.3 and 1.4 show the position and extent of these basins of the Nile today. The basins stand out in the longitudinal section of the river (Fig. 1.4) as flat stretches or landings with very little slope, which are connected today with rivers which have considerably steeper slopes.

In the Equatorial Plateau lie the basins of lakes Victoria, Kioga and Albert which slope gently toward the north at an average rate of one meter for every 20 to 50 kilometers of stretch. In contrast the swift rivers which connect these lakes fall at an average rate of one meter for every kilometer or less of length. To the north of these lakes lie the enormous Sudd and Central Sudan basins which extend for a distance of 1800 kilometers from Juba to Khartoum, and which form a gently sloping region with the phenomenally small rate of slope of one meter for every 24 kilometers of stretch. The river which connects this basin with Egypt is the swift Nubian Nile with its rapids and cataracts; it falls at the rate of one meter for every six kilometers of stretch.

The past six million years which witnessed the making of the Nile were characterized by major climatic fluctuations that affected the entire globe. The polar ice sheets and mountain glaciers advanced and retreated many times during this period. These were accompanied by great fluctuations in temperature, atmospheric pressure gradients, rainfall patterns and sea level

— all of which left their impact on the history of the Nile. In addition, the past six million years witnessed great earth movements and volcanic activity that affected in particular the area of the headwaters of the Nile. The reactivation of the great African Rift Valley (Fig. 1.6) tilted mountains and redirected the drainage of both the Equatorial and Ethiopian Highlands toward the Nile. Previous to these movements most of the drainage of these plateaus had been directed to the Congo basin and to the Red Sea and the Indian Ocean respectively. Effective also in determining the course of the tributaries that came from these plateaus was the spewed volcanic material that spilled over the surface of these plateaus in great quantities during the years of formation of the river; it blocked the way of many of the tributaries forcing them into new courses and determining their paths.

Figure 1.1 (top) is an attempt to reconstruct the shape of the basin of the Nile before the African rift had taken its present shape and at the time the Egyptian river started to excavate its channel some six million years ago. The Red Sea was then a small longitudinal trough and the Equatorial Plateau was high and without lakes. Most of the drainage of the Equatorial Plateau was directed toward the Congo basin or the Indian Ocean, but part went northward toward the great Sudd lake which occupied a large part of the modern Nile Basin. Egypt was separated from sub-Saharan Africa by the high Nubian massif, and the new Egyptian river that was forming was not connected with Africa. Figure 1.1 (bottom) attempts to reconstruct the Nile Basin some five million years later after the great African rift had taken its modern shape. The Equatorial Plateau was cut across by two rift systems, a western rift which was filled with lakes Tanganyika, Kivu, Edward and Albert and an eastern rift which continued into Ethiopia and was filled with lakes Turkana and the series of Ethiopian lakes. Lake Victoria appeared for the first time in the sag between the two rifts. A large part of the drainage of the Ethiopian plateau was diverted toward the Nile Basin.

It took a long time for the water that was directed toward the Nile Basin to find its way to the Mediterranean Sea. It had first to cut a channel through the Nubian swell, which was considerably higher than today. The swell presented a formidable barrier for the water accumulating in the basins further south. A glance at the modern Nubian Nile shows that the river is still struggling through this stretch; its course runs in great swings and is obstructed by rapids and cataracts.

The excavation of the channel of the Nile in Egypt was in response to a unique and unusual event which caused the Mediterranean Sea to become a huge dry desert some six million years ago. The severing of that sea from the world's oceanic system through the elevation of the Gibralter Strait converted the Sea into a lake which later dried up as its waters evaporated under the scorching sun of that episode. The dry Mediterranean was some three to four thousand meters deep. This caused the few rivers that drained into it to cut down their channels to this new depth. In the case of the Nile the channel was deepened to as much as four kilometers in its northern reaches; the early Nile (or Eonile) formed a canyon that was "just as awe-inspiring and as deep as the modern Grand Canyon of Arizona". This newly formed canyon soon became the site of sedimentary fill as the rising waters of the regenerated Mediterranean, which obtained access to the waters of the Atlantic some five and a half million years ago, entered into it converting it into a gulf. A major river (the Paleonile) pushed its way into the gulf and filled it with sediments. It is highly probable that the rivers which occupied the early canyon had local sources; they had not yet developed an African connection. This phase lasted for about four million years. It is separated from our time by at least two million years.

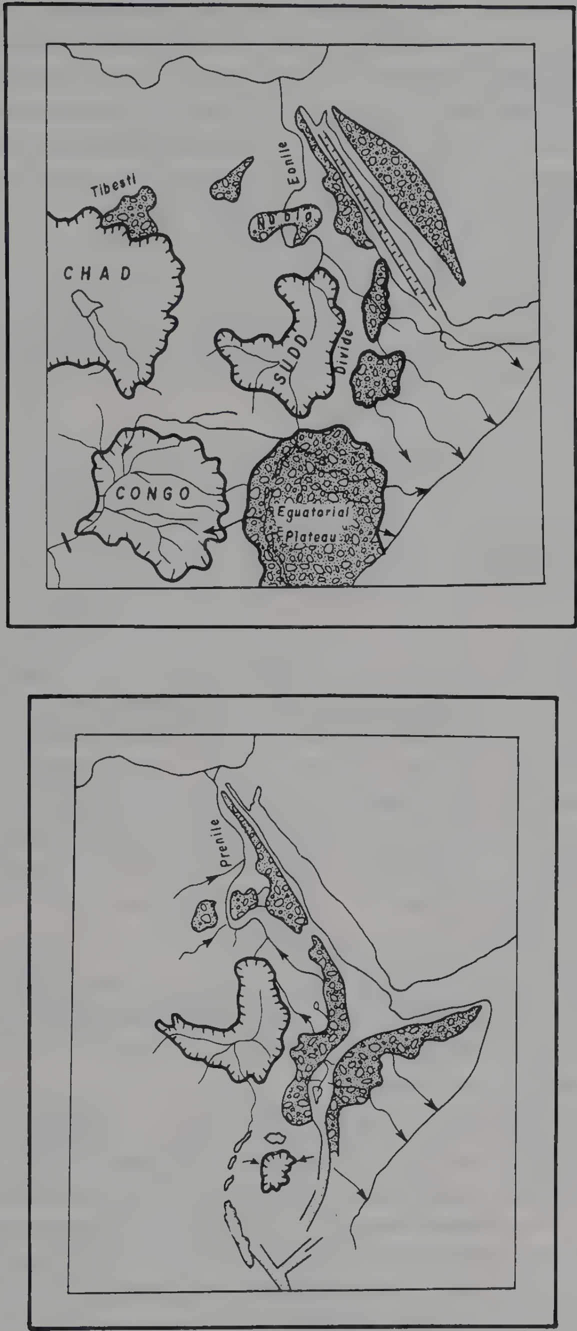

Fig. 1.1. A reconstruction of the Nile basin: (Top) 6 million years ago; (Bottom) some 5 million years later when the African Rift assumed more or less its present shape.

A long time passed before the first river with a sub-Saharan African connection came to Egypt. This major breakthrough in the history of the Nile is estimated to have occurred some 800,000 to 700,000 years ago. The river, which we shall call the Prenile, was the result of the new drainage pattern which developed after the relief of Ethiopia and also that of the Lake Plateau had approached their present-day shape as a result of the great earth movements of that age. These earth movements resulted in the development of Lake Tana and the Main Ethiopian Rift and also in the appearance of Lake Victoria. The new river was a vigorous and competent river which carried an enormous quantity of coarse sands and gravels that were deposited on its large flood plain and delta, both of which exceeded in extent those of the modern Nile. It was a river with a copious supply of water. Its sediments are coarse, massive and thick. They crop out in a most conspicuous way along the banks of the Egyptian Nile and delta margins forming an important element in their landscape. The Prenile was indeed the most effective river in outlining the landscape of the modern valley and delta. Its outcrops of sand provide the towns and cities of Egypt with their building material.

After the cessation of the flow of the Prenile some 400,000 years ago, a considerably less competent river, the Neonile, broke into Egypt. The connection of this river with its African sources was tenuous and sporadic. It lost its African connection many times and in no instance did it come back with the length of duration or the competence of the Prenile. The Neonile continues to this day and is of especial interest as it spans the time of man's occupancy of the land of Nubia and Egypt.

Three sets of events can be distinguished during the evolution of the Neonile. The earliest set of events (?400,000 to ?200,000 years ago) was associated with a wet interval that set over Egypt, during which the African connection was severed and ephemeral rivers fed by local rains filled the Egyptian valley of the Nile. This wet interval was interrupted by a short arid episode in Egypt in which the Egyptian Nile resumed its connection with Ethiopia bringing about a river, the Dandara (alpha Neonile), which was totally different from the Prenile; its sediments were fine-grained. It had a regimen which has become the pattern of all the rivers of Egypt with African connection since that time. The wet interval of this early set of events saw the appearance of Early Paleolithic man on a grand scale in Egypt.

The second set of events (?200,000 to ?70,000 years ago) was associated with another wet interval which came shortly after the first interval. Local winter rains supplemented a low and erratic river with an African connection during this wet interval which saw the appearance and spread of Middle Paleolithic man in Egypt.

The third set of events (?70,000 years ago to present) was associated with the last glacial period and the period that followed the retreat of its ice sheets some 10,000 years ago. This latter period is known as the Holocene epoch. During the height of the glacial period the Lake Plateau received considerably lesser rains. The equatorial forest had disappeared, the Sudd region was dry and the White Nile was obstructed by dune fields. During this, glacial Egypt was also arid and the desert, which was roamed by early man during the earlier wet intervals, was abandoned as a habitation site. During the glacial period two successive rivers, the so-called beta Neonile (?70,000–25,000 before present) and gamma Neonile (20,000–12,000 before present), came to Egypt from the Ethiopian Highlands. Having only one monsoonal source, the rivers were humble and seasonal probably drying up during the winter. They came laden with sediment which was piled high along the banks of the river in southern Egypt. The piling up of the

sediments of these two rivers is difficult to explain and could have been the result of impediments, which have since disappeared, that obstructed the flow of the river in southern Egypt. The sea level during the last glacial, when these rivers were active, was low, probably as low as one hundred meters below the modern sea level. With such a low sea level the river should have been deepening its channel rather than building its bed. In the north the beta and gamma Neoniles deepened their channels.

With the retreat of the ice there was a period of increased rainfall over the headwaters of the Nile raising the levels of the Equatorial lakes and causing major vegetational changes. Grasses, which prevailed during glacial times, were replaced with forests. Rains came first to the Equatorial Lake Plateau region and caused the overflow of Lakes Victoria and Albert into the Nile drainage system for the first time. This flow, which passed unhampered along the then dry Sudd region, reached Egypt in great quantities and generated a period of wild floods which lasted for five hundred years from 12,500 to 12,000 years ago.

At about 10,000 years ago the rains came to the Ethiopian Highlands, northern Sudan and southern Egypt. The rain front which extended northward to the middle latitudes of Egypt lasted for about 6500 years. With sources in both the Lake Plateau and the Ethiopian Highlands the new river became perennial assuming a regimen similar to that of today. The additional rains that came from northern Sudan and southern Egypt swelled the river. This post-glacial wet phase is known in Egypt and the Sudan as the Holocene (Nabtian) Wet Phase. It was during that phase that the modern Nile was born. With a copious flow of water and a sea level still low the new river incised its bed and graded its channel by removing the impediments which obstructed its course. As the ice retreated and the sea level rose the river started building up its bed in a process that continues still today. The oldest of the silt beds of the modern agricultural layer of Egypt are about 7500 years old.

Below is a table of the major events which shaped the river Nile.

Dates (in thousand years)	River	Events
6000–5400	Eonile	Nile canyon forms in response to a desiccated Mediterranean.
5400–3300	Gulf Phase	Rising waters of the regenerated Mediterranean fill the canyon converting it into a gulf.
3300–1800	Paleonile	Local river occupies the gulf & fills the valley with sediments.
1800–800	Desert Phase	Egypt converted into desert. River stops flowing.
800–400	Prenile	First Egyptian river with an African connection established. River exceedingly competent.
400–present	Neonile	A less competent river with an African connection dominates the scene. Ebbs & flows many times. The first (or alpha Neonile) interrupts a wet phase (400,000–200,000 years) followed by an erratic Nile (200,000–70,000 years), then by the seasonal beta and gamma Neoniles (70,000–12,000 years) & finally by the modern perennial Nile (12,000–present).

Fig. 1.2. The Nile and surrounding countries.

1

INTRODUCTION

The River Nile is a salient geographical feature of North Africa. It is the only river which is able to carry part of the drainage of Equatorial Africa through the barren and rainless Sahara to the Mediterranean Sea. Figure 1.2 is a map drawn on an equal area zenithal projection, to show the position of the river and its environs in their true relative proportions and directions from Egypt as a center. It shows the Nile as the only river which flows into the southern Mediterranean. In its journey across the Sahara from the Atbara to the Mediterranean the Nile flows for a distance of close to 2700 kilometers without receiving a tributary or any sizeable quantity of water. The journey that the river makes across the rainless Sahara is remarkable and unique. Most other rivers would not have been able to pursue their course for that long distance without dissipating their waters, depositing their load and fanning out into an interior delta. The modern Gash and Barka rivers which emanate from the Ethiopian Highlands are examples of rivers which could not pursue their course for any distance beyond the last point at which they had a water supply. After leaving the Ethiopian mountains and entering the arid Erithrean and Sudanese plains these rivers become sluggish as they lose their water through seepage and evaporation until they fan out in interior deltas. The Atbara and the Blue Nile behaved in a similar fashion during arid phases of the past when the amount of water they carried was small.

Exceptional geological events made possible the journey of the Nile in the arid wastes of the Sahara. The most important of these events were those which allowed the tapping and integration of the multiple sources of the present-day river into one system. The river receives its water from the Ethiopian Highlands with its summer monsoon rains where the rivers are highly seasonal with a ratio of peak flow to low flow of forty to one. It also receives its water from the Equatorial Lake region with its year round rains where the river flows without great seasonal changes; the ratio of the mean peak flow to the low water flow is five to two. The western mountains of the Lake Plateau are among the wettest parts of the earth with approximately three hundred and sixty days and five meters of rain each year. This extremely fortunate meteorological accident made possible the continual flow of water of the Nile all year long even when the rivers of the Ethiopian Highlands dry almost to a trickle.

The relief of the Lake Plateau and the Ethiopian Highlands was shaped by relatively recent events which directed their drainage toward the Nile Basin rather than the Red Sea or the Atlantic Ocean as was the case prior to the evolution of the modern river. It is remarkable that almost all the drainage of the Ethiopian Highlands and the Red Sea hills goes toward the Nile Basin rather than the Red Sea which is left without a single flowing river. In this respect the Red Sea is unique and without rival. Events also shaped the delivery system through which the newly directed

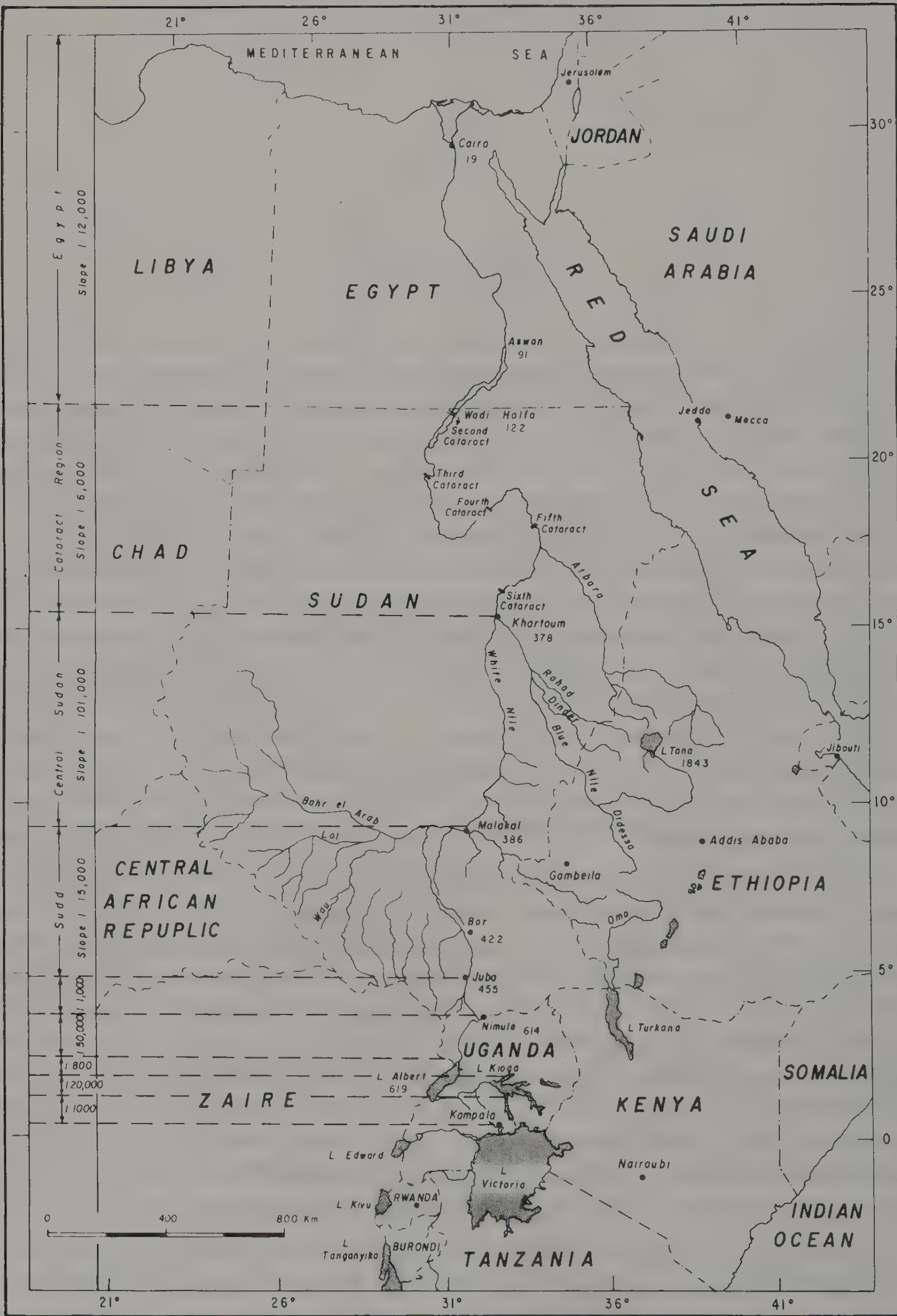

Fig. 1.3. Map of the Nile and its tributaries, with flood levels in meters, showing the different physiographic regions of the basin.

drainage reached the Mediterranean. We shall go into greater detail as we relate the history of the river.

The Nile has a very small discharge when compared to its length or the area of its basin. A glance at the following table shows that the discharge of the Nile is very humble indeed. The length of the Nile is 6825 kilometers, the longest river in the world, and its drainage basin is 2.96 million square kilometers, the equivalent of one tenth of the African continent; yet its discharge is barely equal to the Rhine whose drainage basin is almost one thirteenth of the drainage area of the Nile. The paucity of the Nile waters in comparison to other rivers of the world is due, to a large extent, to the small amount of discharge received per unit area of drainage; a large part of the basin is almost totally rainless.

The Nile in comparison to other major river systems

River	Length (km)	Drainage area (10^3 km^2)	Annual Discharge (10^9 m^3)	Discharge per unit area (10^3 m^3/km^2)
Nile	6825	2960	84	28
Amazon	6700	7050	5518	728
Congo	4700	3820	1248	326
Hoang Ho	4630	673	123	182
Mekong	4200	795	470	590
Niger	4100	1220	192	157
Mississippi	970	3270	562	170
Danube	2900	816	206	252
Zambezi	2700	1200	223	185
Rhine	1320	224	70	312

Figure 1.3 is a map of the present-day Nile and its tributaries, with the flood levels of the river at a number of principal points. Along its length from Lake Victoria to the Mediterranean Sea, the slope of the river shows marked changes passing through several gently-sloping "landings" which are connected by steeply-sloping rivers. Figure 1.4 is a longitudinal section of the river from the equatorial lakes to the sea. It shows five "landings" which are from south to north: Lake Victoria, Lake Kioga and the stretches from Lake Albert to Nimule, from Juba to Khartoum and from Wadi Halfa to the Mediterranean. The stretches of the river which connect these "landings" are extremely steep, obstructed by waterfalls and cataracts, and youthful in appearance and age. Before the river assumed its present-day course, the different "landings" seem to have formed independent basins which were disconnected. Each of these basins had its own peculiarities with regard to size, cross section, the amount of water it held and, more importantly, its geological history and evolution.

The four southern "landings" seem to have formed interiorly-drained basins for a long time. Their access to the sea throughout most of their history was tenuous and intermittent. At times of high rainfall they swelled, assumed enormous dimensions and overflowed their shores to other basins; at times of low rainfall they shrank or dried up completely. The three southernmost "landings" belong to the hilly Lake Plateau region which has a high rainfall (1200 millimeters/ year). The fourth "landing", which stretches from Juba to Khartoum, formed another enormous interior basin which occupied a large part of the Sudan. This basin is drained today by the river

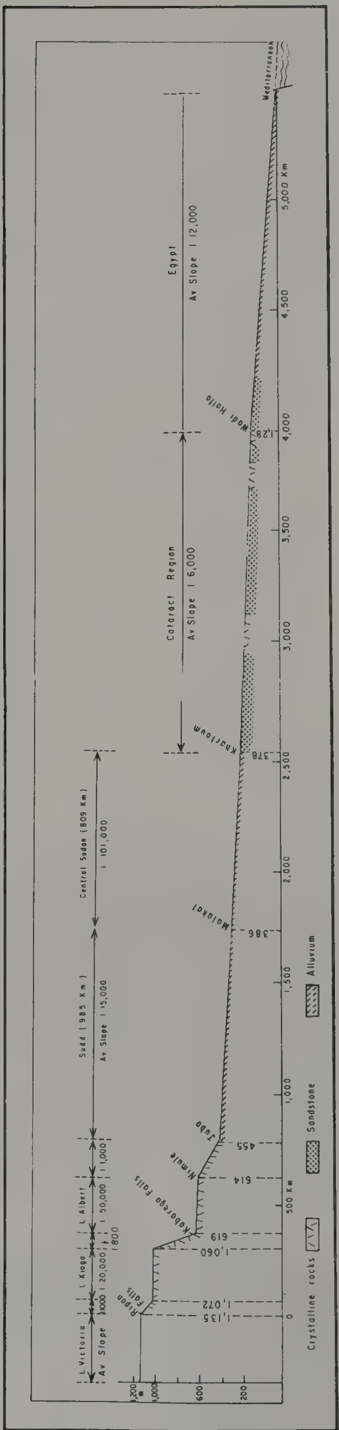

Fig. 1.4. Longitudinal section of the present-day Nile from Lake Victoria to the sea.

across the Nubian swell into Egypt and the Mediterranean by way of a series of cataracts. The interconnection of these different basins and their integration into one drainage system is a relatively recent phenomenon, for the Nile is not one river; it is in reality a collection of basins and rivers which were connected together to form the present-day system at a very late date. There is now good evidence that the River Nile evolved to its present-day shape as recently as 10,000 years ago.

The origin of the numerous basins which constitute the modern river is closely tied to the history of the African continent. The Sudd basin, for example, is one of the old basins which evolved, like many other interiorly-drained basins of that continent, as a result of the extended history of erosion which affected the elevated lands of Africa. Figure 1.5 shows the major basins of Africa and their bounding swells. While some of these obtained access to the sea, some are still interiorly-drained, acting, in fact, as receptacles for the material eroded from the intermittently uplifted swells of the coalescing plateaus which surround them. A remarkable example of these interiorly drained basins with no outlet to the sea is the Chad Basin. Lake Chad, fed by the Shari River from the swell to the south, is a shallow expanse of swamps and open water with no visible outlet. Another example is the vast depression of El-Juf which lies to the north of Timbuktu in one of the most awesome parts of the Sahara, which, until recent years, had been the least accessible and least known. On the other side of the equator lies the interiorly-drained basin of the Kalahari Desert, partly grassy steppes and partly desert, which drains to the north at the brackish swamps of Lake Ngami.

In striking contrast are the copiously watered basins of Africa which broke their barrier and obtained access to the sea. Notable among these are the Congo River basin which escapes to the Atlantic across the western swell by a series of cataracts, the Cubango Basin which is drained by the great Zambeze River and the Karroo Basin which is drained by the Orange River. All these rivers have an east–west direction and each drains one basin. In contrast, the River Nile, which has a more complex history, has a north–south direction, drains more than one basin and spans more than 35° of latitude. It drains an area of close to three million square kilometers and connects regions which are different from one another in relief, climate and geologic structure. The main sources of the present-day Nile are the Equatorial Lake Plateau, which constitutes the southern swell bordering the Sudan basin, and the Ethiopian Highlands which forms part of the east African coalescing series of plateaus traversed by the great African Rift.

2

THE LAKE PLATEAU

The southern basins of Lakes Victoria, Kioga and Albert belong to the Equatorial Lake Plateau whose present-day drainage system is of relatively recent origin. It seems to have developed as a result of the interconnection of these lakes and their integration into one system. The evolution of the Lake Plateau is closely tied to the development of the great African Rift. A rift is a long, let-down valley bordered by fault scarps which is formed as a result of earth movements. The African Rift (Fig. 1.6) is truly one of the most spectacular in the world. It extends for more than 2880 kilometers and, although it does not constitute one long continuous trough, its individual parts form a series of a single closely related system. The length of the rift could well be doubled if the Red Sea depression and its continuation into Syria, via the Dead Sea rift, were to be included. The latter, however, are of a different origin. The strictly African Rift is made up of a southern section, occupied by Lake Malawi (Nyasa) and its bifurcations which start at the Rukwa and Ruaha Lakes, and continue northward to form a western branch and an eastern branch to the west and east of Lake Victoria. These deep and narrow troughs of the Rift Valley are studded with lakes. The western branch of this rift system cuts across the western swell of the Lake Plateau and includes from south to north; Lakes Tanganyika, Kivu, Edward and Albert which are towered by great mountain ranges. The most spectacular of these are the Mufumbiro and the Ruwenzori ranges. The uplifted massif of the Ruwenzori, which today forms part of the Nile drainage system, lies between Lakes Edward and Albert. The Mufimbiro is a volcanic range which lies some 70 kilometers south of the Equator in the State of Burundi, between Lakes Kivu and Edward. At least five of its peaks are active volcanoes. Because the range cuts at right angles across the north–south line of the rift its clouds provide water for two different rivers: streams from its southern slopes pour into the Congo system, and streams from its northern and northeastern slopes feed the Nile. In the Mufumbiro range and its vicinity there are many small lakes in the craters of extinct volcanoes both inside and just outside the rift valley. In certain regions especially in the highlands of southwest Uganda and the neighboring northeast Rwanda, lava flows during the late Pleistocene have dammed river valleys and formed fjord-like lakes such as Lakes Bunyoni and Bulero.

The eastern system of the rift cuts across the eastern swell of the Lake Plateau and extends into the Ethiopian Highlands and the Red Sea and includes Lakes Ruaha, Eyasi, Natron, Magadi, Naivasha, Baringo, Turkana (Rudolf), Stephanie, Chamo, Abaya, Shala, Langana and Zwai.

Lake Victoria lies in the midst of the Equatorial Lake Plateau which includes the central plateaus of Tanzania, Kenya and Uganda (the so-called Tanganyika craton). This vast region attracted the attention of a large number of geologists (Wayland 1921; Kent 1044; Dixey 1946;

Fig. 1.5. Map showing in a generalized way the tectonic basins of Africa and intervening swells (after Holmes 1965).

Doornkamp & Temple 1966 and others). It was reduced to a flat area about 10 to 15 million years ago, and has since been intermittently elevated by about 2000 meters and fractured and trenched by the rift valley systems. The lake lies in the shallow crustal sag between the eastern and western swells which were incised at their crest by the deep rift valleys (Fig. 1.7). The lake, therefore, has a different origin than the lakes of the rift valley system. It differs from these lakes in having gently shelving shores and shallow depth inspite of its enormous area; its greatest depth is no more than 80 meters. Along the shelving shores of the lake the gradients are small and much water is held up in shallow swamps blocked with vegetation; in Uganda alone there are more than 6500 square kilometers of permanent swamp.

A significant feature of the Lake Plateau is the characteristic rise of the surface toward the edges of both the eastern and western rifts. These edges now form the divide marking the boundary between the Nile and the adjacent basins. The upwarping in the west is so recent that

Fig. 1.6. Map of the African rift valleys from Zambesi to Ethiopia.

rivers which once flowed into the Congo basin are now reversed and flow toward the Nile Basin. River Katonga, which drains into the northwestern corner of Lake Victoria, River Kafu, which forms part of the curiously-shaped Lake Kioga and the impressive River Kagera are reversed channels. All three rivers formerly formed part of the drainage of the Congo basin. Lake Victoria, therefore, owes a large part of its supply, if not its origin, to the ponding of the originally westward flowing rivers as they were reversed. The exact age of the ponding is not established but could well be of middle if not late Pleistocene age (Livingstone 1976).

For a long time Lake Victoria continued to be a closed lake without an outlet to the main Nile, and it was only about 12,500 years ago that the lake overflowed its shores in the north over the Ripon and Owen Falls to the swampy Lake Kioga and from there over the Kabarega (Murchison) Falls to Lake Albert. The study of a core drilled for a depth of 18 meters in Lake Victoria shows that the water level 14,000 years ago was at least 26 meters lower than it is today (Kendall 1969). The pollen spectra of that time were dominated by grasses; the vegetation was savanna; the climate was considerably drier than today. When the lake level rose to establish the Nile outlet 12,500 years ago, however, the pollen spectra indicated the presence of rain forest trees. The frequency of these trees increased gradually at first, had a temporary setback around 10,000 years ago, but increased after that until they reached their maximum abundance from 9500 to 6500 years ago. About 6500 years ago the climate became drier or more seasonal or both, and indicators of semi-deciduous forest increase at the expense of evergreen forest. Evidence from Lake Victoria itself does not indicate how long before 12,500 years ago the lake was closed or at least had not supplied water to the Nile (Beadle 1981). It is possible that the lake had never supplied water to the Nile before 12,500 years ago. The presence of extensive evaporites along the White Nile, dated between 25,000 and 40,000 years ago, suggests that major contributions of water from the Lake Plateau may have been rare in the late Pleistocene (Adamson & Williams 1980). Recently the Duke University Project PROBE confirmed the presence of a consistent surface of erosion at 14,000 years ago when the lake almost dried up. The conclusion is based on the work of the project which acquired close to 100 kilometers of multichannel seismic data and many more line kilometers of high resolution echo-sounder data in Lake Victoria (Scholz, Rosendahl, Versfelt & Rach 1990).

The two southern gently-sloping basins of Lakes Victoria and Kioga (Fig. 1.7) are connected today by the steep Victoria Nile which leaves Lake Victoria at the Ripon Falls and stretches for a distance of 64 kilometers. It falls from a height of 1135 meters above sea level at its outlet from Lake Victoria to a height of 1072 meters at its entrance to Lake Kioga with a slope of 1 : 1000 or a fall of one meter for each kilometer of length. In the Kioga plain, which stretches for about 236 kilometers, the slope is very gentle falling about one meter for each twenty kilometers of stretch; it falls from a height of 1072 meters above sea level at its southern end to 1060 meters at its northern end.

The Lake Kioga "landing" is connected to Lake Albert by another steeply-inclined stretch about 68 kilometers in length. This stretch is obstructed by numerous falls the most important of which are the Karuma and the Kabarega (Murchison) Falls. In the spectacular Kabarega reach the river races through a funnel of rock six meters wide and spills out in two separate arms that thunder down about 40 meters to explode on the rocks below. The stretch from Lake Kioga to Lake Albert has a slope of 1 : 180 or a fall of 5.5 meters for every one kilometer of length.

Fig. 1.7. Map of the Lake Plateau Basin.

The Lake Albert "landing" extends beyond its exit for a distance of two hundred and twenty-five kilometers to the town of Nimule on the Uganda–Sudan border. In this stretch, which seems to be genetically connected to Lake Albert forming part of its basin (Fig. 1.7), the river flows placidly between marshy banks. It meanders in a broad, gently-sloping and well-defined valley where it is fringed by lagoons and swamps. The width of the river in this stretch varies from 100 to 300 meters and the swamps and lagoons occupy an area of about 380 square kilometers. The slope of this stretch is so small that it falls less than two centimeters for every kilometer of its course. The "landing" falls from an elevation of 619 meters above sea level at the southern part of Lake Albert to 614 meters at Nimule.

Until very recent time Lakes Albert and Edward were probably closed lakes like the present-day Lakes Kivu and Tanganyika of the western Rift System. They were connected to each other

and to the main Nile during periods of high rainfall. Indications are that Lake Albert was connected to the Nile from at least 28,000 to 25,000 years ago, from 18,000 to 14,000 years ago and since 12,500 years ago. During the dry periods its level fell at least 56 meters leaving no more than a level of 23 meters of water in the lake. Lake Edward must have been connected with Lake Albert and thus with the Nile at least 6000 years ago. This conclusion is based on the presence of a fossil fish fauna of nilotic origin in a raised beach of the lake, dated between six and eight thousand years ago. The fact that the fish fauna of the present-day lake is largely endemic, with no trace of nilotic fishes (such as perch), indicates that the lake lost this connection after the formation of that beach. It is possible that a violent volcanic eruption caused the disconnection and prevented the free exchange of the faunas of the two lakes. Recolonization from Lake Albert has been prevented by the Semliki rapids, and the modern fauna, though abundant, is relatively poor in species. The small number of endemic species suggests that isolation was recent and that the origin of the Semliki rapids may have been contemporary with the volcanics.

A prominent feature of the western rift is the towering mountain of Ruwenzori (the "Mountains of the Moon" of the Arab travellers), upthrusted between Lakes Edward and Albert, which is by far the highest non-volcanic mountain in Africa. It rises to snow-clad peaks up to 5122 meters above sea level or about four kilometers above the level of the plateau. Indications of its recent uplift are numerous. The mountain today supports 40 glaciers and supported many others in the past. Many of the peaks of the Ruwenzori are named after the early explorers of Central Africa: Emin, Gessi, Speke, Stanley, Baker and di Savoia. The highest peak (5122 meters) is named Mount Stanley after the first European who sighted the mountain during an expedition in 1887–1888. Later expeditions explored the lower reaches but it was not until the British Museum Expedition of 1935 that the main peaks were climbed, accurately mapped and surveyed. During the last glacial age, which ended some 15,000 years ago, there seems to have been a temperature lowering of 4.2 degrees centigrade in Ruwenzori and a considerable lowering of the snow line. The glaciers of the Ruwenzori are discussed in the Oxford University doctoral dissertation of Osmaston (1965) and in Livingstone (1980).

The connection of the Lake Albert–Nimule stretch to the main Nile at Juba is affected over a series of rapids extending for about 155 kilometers by a river which, at Nimule, turns sharply and abruptly from an east to a northwest direction for about 70 kilometers. The river follows the course of the Aswa wrench fault before it turns northward to Juba. The deflection of the river in this stretch presents one of the clear examples of the control of the geology of the area over the course of the river. The fall of the river is 1 : 1000 or approximately one meter for every kilometer of length.

3

THE SUDD AND THE CENTRAL SUDAN BASIN

The Sudd and the Central Sudan basins form a gently sloping region of enormous dimensions which extends for about 1767 kilometers from Juba to Khartoum (Fig. 1.8). The southern part, known as the Sudd, extends from Juba to Malakal for a distance of 809 kilometers. It has a slope of 1 : 15,000 or one meter for every 15 kilometers of length. Its gentle slope and copious supply of water, coming from both the extensive rains of this region and the drainage of the Lake Plateau, force the river in this stretch to overflow its banks and resist being confined to one channel. Extensive swamps with a thick mat of vegetation spread out on either side of the river. The area of the permanent swamp varies from year to year depending on the amount of rain. It averaged between 6500 and 8000 square kilometers prior to the great 1961 surge in the rains of the Equatorial Plateau. It increased to 30,000 square kilometers after 1961 and has remained since then between 20,000 and 30,000 square kilometers (Sutcliffe & Lazenby 1990). The northern Central Sudan basin, occupied by the White Nile, has the phenomenally low slope of 1 : 101,000 or one centimeter for every kilometer of length.

The phenomenally flat areas of the Sudd and Central Sudan basins led many authors (Willcocks 1904; Lawson 1927; Ball 1939) to believe that these basins may have formed a vast lake in the past. Willcocks was of the idea that the lake covered only the Sudd region, while Ball extended the lake to cover also the Central Sudan Basin and assumed its limit to have been the 400-meter contour which at present is the elevation at which the Sudd-growth stops. The lake as such would have had a length of some 1050 kilometers, a maximum width from east to west of 530 kilometers and an area of about 230,000 square kilometers. The lake with this extension would have received the drainage of the Blue Nile and most likely the Sobat.

There is ample evidence that both the Sudd and the Central Sudan basins formed for a long time a series of closed lakes with no outlet to the sea, and which at times of higher rainfall joined one another to form one enormous lake. Recent seismic surveys conducted by oil companies in the Sudd region show that the Sudd represents in fact an old interiorly-drained tectonic basin (the so-called Bahr el-Arab Rift) which had been the site of lacustrine and alluvial sedimentation since at least the early Tertiary (40–50 million years ago). The thickness of the sediments in this basin reaches ten to eleven kilometers. The Central Sudan region is another tectonic basin (the so-called White Nile Rift). It seems to have had a similar history to that of the Sudd region. A large part of its sediments came from the drainage area of Wadi Abu Habl in the northwest. Both basins were occupied by closed lakes which expanded and overflowed their banks during wetter periods and dried up or were reduced to a series of closed saline lakes during periods of low

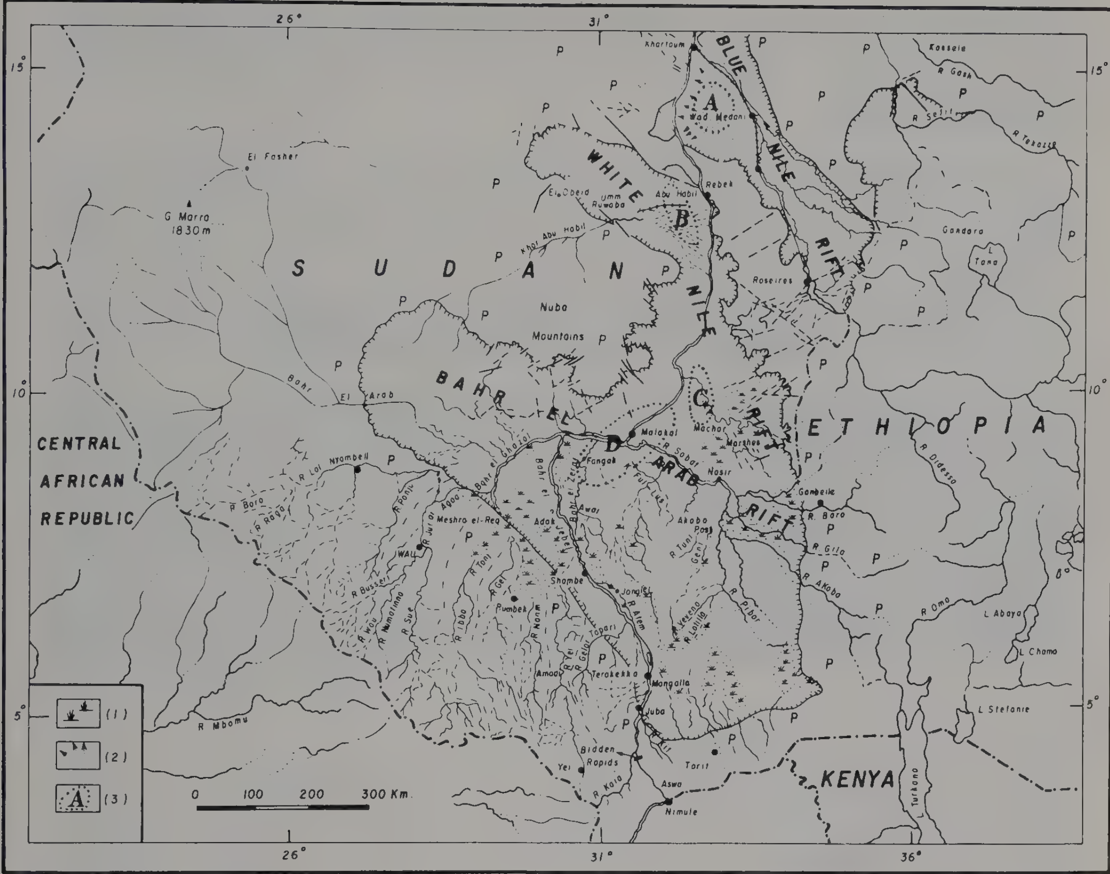

Fig. 1.8. Map showing the extent of the former Lake Sudd which filled the White Nile and the Bahr el-Arab rift systems with alluvial, lacustrine and swamp deposits. P. Precambrian crystalline rocks, 1. swamp, 2. subrecent alluvial fans of Wadi Abu Habl and the Blue Nile rift system, 3. saline zones: A. Gezira, B. Nuba, C. Adar, D. Sudd saline zones (after Salama 1987 with modifications).

rainfall (Salama 1987). Several of these saline groundwater bodies in the Gezira, Nuba, Adar and Sudd regions are described (Fig. 1.8).

While it is difficult to reconstruct fully the early geologic history of the Sudd and Central Sudan basins, it is certain that the lakes which occupied them shrank during the last glacial which had its maximum some 15,000 years ago and that the greater part of their surface was probably covered with active dunes. Similar conditions may have also prevailed during the period between 40,000 and 26,000 years ago (Williams & Adamson 1980).

The lakes seem to have increased in size during the wet phase that immediately followed the retreat of the ice of the last glacial age and seem to have reached their maximum size about 12,500 years ago. At that time the levels of all the lakes of the African rift were at their maximum and the Victoria and Albert closed basins overflowed their banks and drained into the Sudd Lake which probably attained its maximum extension then. It was also during that time that the lake

opened up and drained through an outlet to the north and ultimately into the Egyptian Nile and the Mediterranean Sea. It must be noted here that the Sudd–Central Sudan basin must have opened up in earlier times, as will be shown in later sections of this chapter, and that this outlet had frequently silted up.

The outlet through which the lake drained to the north was most likely the Shabluka reach (85 kilometers north of Khartoum) better known as the sixth cataract even though it is not a cataract at all. It is, in fact, a stretch of the river in which navigation is rendered difficult, especially at low Nile, by the abundance of rocky islands and by the existence here and there of small rapids (Fig. 1.9). The Shabluka reach seems to have been formed by the cutting of the hilly country which lies to the north of the island of Royan. After running for about 21 kilometers in an open country from Wadi Ramli to just beyond the island of Royan, the river passes through a reach of about 12 kilometers where it flows in a deep narrow gorge through a tract of low hills. After emerging from that gorge the river runs for about 27 kilometers where it again traverses more open country. It is in this third or lower reach that the river's course is most thickly beset with islands. The Shabluka gorge proper has a width of 400 meters and is shut in between steep rocky slopes rising to heights of more than 100 meters on either side. The Shabluka seems to have formed the gate through which the waters of the Central Sudan had reached the Mediterranean. The present-day channel seems to have been formed some 12,500 years ago when the floods were high, the river having abandoned its earlier and easier course through the lower country to the east which apparently had silted up during an earlier period of lower flow.

4

RIVERS OF THE ETHIOPIAN HIGHLANDS

The three major tributaries of the Nile which emanate from the Ethiopian Highlands, the Atbara, the Blue Nile and the Sobat, are highly seasonal rivers with a ratio of peak flow to low flow of about forty to one, and a peak sediment concentration at their confluence with the Nile of about 4000 milligrams/liter in August as against only 100 milligrams/liter in June. Such seasonality is related to the rainfall regime in the Ethiopian Highlands where 90 percent of the annual precipitation of rain falls between June and October with a peak during July and August. The average rainfall over the Highlands of Ethiopia is 1000 to 1400 millimeters/year, although in the southwest, where the Baro of the Sobat finds its source, the highest rainfall ranges between 1400 and 2200 millimeters/year.

The headwaters of the three rivers lie in the Ethiopian Plateau at heights of 2000 to 3000 meters above sea level (Fig. 1.10). About half the plateau of Ethiopia and Eritrea is above 2000 meters and reaches its highest point in a peak of the Simien Mountains, 4620 meters, just a little lower than Mont Blanc. There are several other peaks in the Simien and Chokai Mountains above 4000 meters on which snow occasionally falls but is not permanent and cannot be said to contribute anything appreciable to the Nile flood. The Plateau country is, on the whole, hilly with grassy downs, swamp valleys and scattered trees. It is cut up by the deep ravines or canyons in which the rivers flow; the largest is the Blue Nile. In places, the river is 1300 meters below the level of the country on either side. Most of the rivers dissecting the country are perennial, though some cease to flow in the dry season. None of the streams, other than the Nile tributaries, reaches the sea. The Gash, which flows past Kassala, the Khor Barka, which comes down to Tokar, the Awash and all the ephemeral rivers of the western slopes of the plateau disappear in sand and flow only for part of the year. Most of Eritrea, from which the waters of these rivers are derived, is much more arid than Ethiopia. It is almost certain that in times past when the rains were heavier these rivers must have reached the Atbara.

The three tributaries of the Nile which emanate in the Ethiopian Highlands arise in a volcanic terrain made up of the older volcanics of the so-called Trap Series and the younger Aden volcanics (Fig. 1.11) formed intermittently from the Miocene to the Pleistocene (27–2 million years ago). The three rivers incise their courses for long distances in these relatively young rocks and must, therefore, be considered of younger age since they must have evolved at a later date than the rocks in which they incised their valleys. Prior to the outpourings of the older lava flows the drainage must have been directed to the east toward the Red Sea; there is no indication of the existence of old gorges or any significant drainage pattern in the west or toward the Nile.

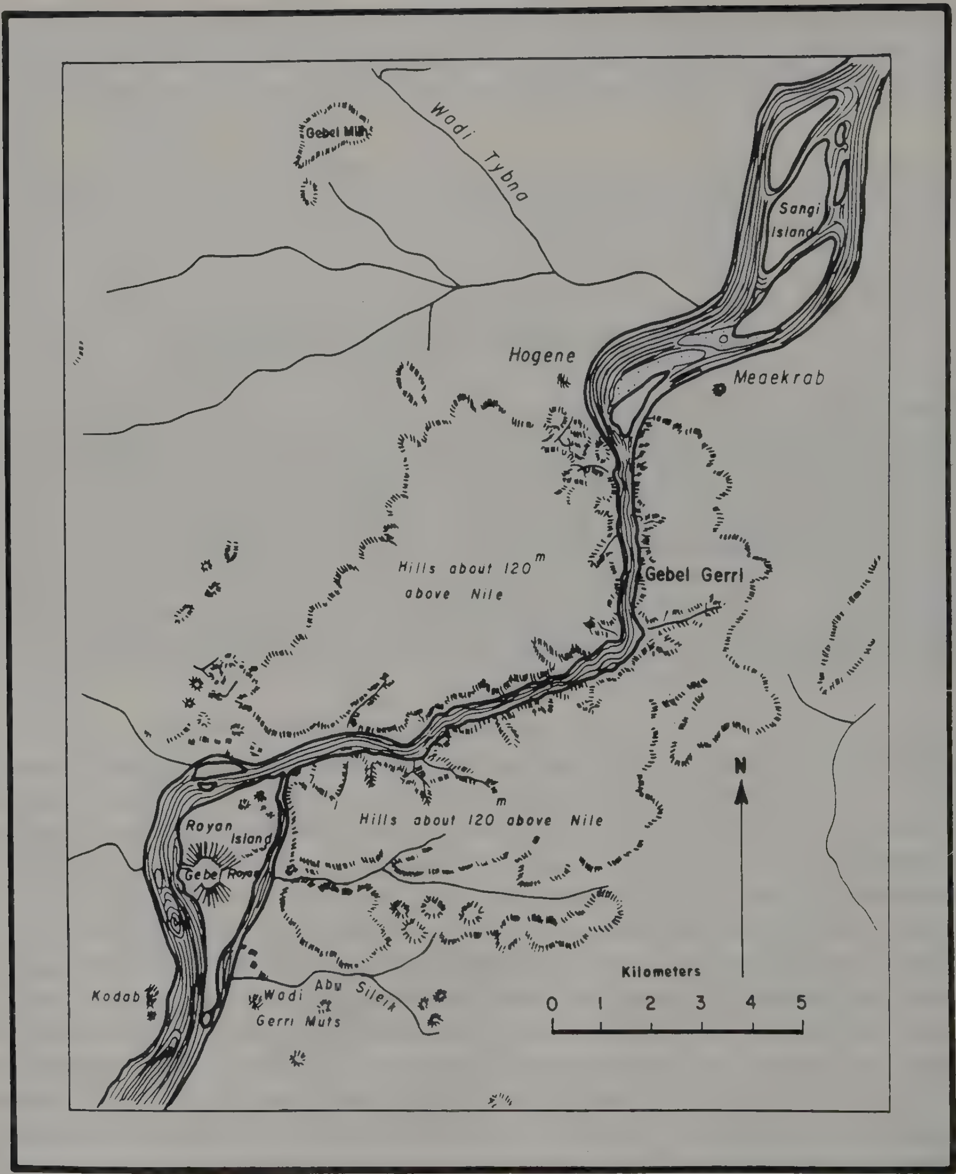

Fig. 1.9. Map of Shabluka Cataract (after Ball 1939).

The three rivers have steep gradients along their course across the Ethiopian Highlands and considerably flatter gradients when they enter the plains bordering the main Nile. As has been stated there is indication that the general westward direction of many of the tributaries of these rivers toward the Nile is a relatively recent phenomenon related to the development of the new relief of the Highlands, resulting from the formation of the Rift Valley which borders the Ethiopian mountains to the east and the spewing of the volcanic rock cover which accompanied and followed the formation of the rift. Today the Ethiopian Rift separates the Nile drainage

basins from the Red Sea and Indian Ocean drainage basins and is drained by systems which have no outlet to the sea. It includes the drainage basins of the Assale which drains into the Danakil depression; the Awash which drains into Lake Abbe; the Upper Rift rivers which drain into the numerous lakes extending from Lake Stephanie in the south to Lake Zwai in the north and the Omo River which drains into Lake Turkana (Fig. 1.10). In the past, prior to the formation of the rift and the development of these closed basins, the drainage of the Ethiopian Highlands seems to have been directed eastward toward the Red Sea or the Indian Ocean. It was only after the tilting of the land and the formation of the Rift Valley that the new modern drainage patterns developed. The exact time at which this change took place is unknown but it must be of very recent date. The age of the rifting, the geomorphology of the Nile tributaries and the small volume of sediment carried by these rivers to their lower reaches attest to their very young age.

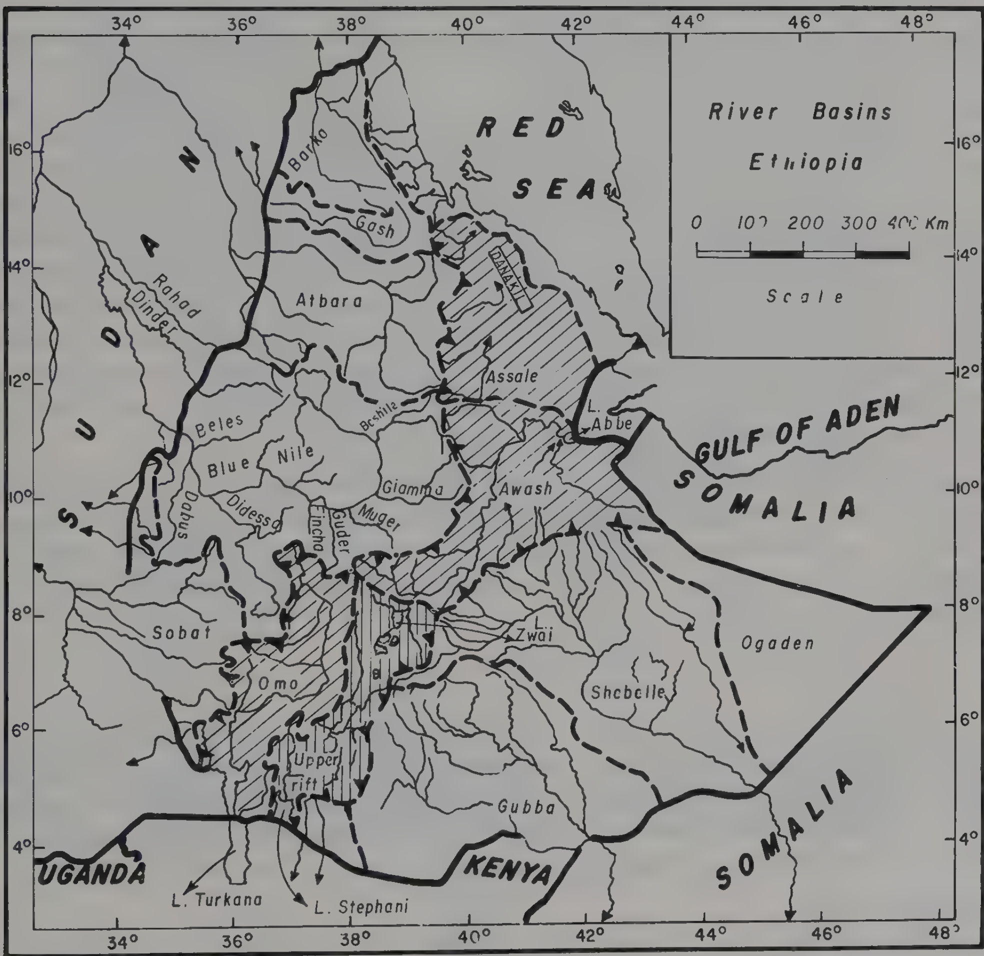

Fig. 1.10. Ethiopian and Horn of Africa drainage basins. Main Ethiopian Rift is shaded and includes the closed basins: upper rift, Omo, Awash and Assale. To the west of the Rift are the Barka, Mereb-Gash and the Nile (the Sobat, Blue Nile and Atbara) basins. To the east and southeast of the Rift are the Red Sea and the Indian Ocean basins of Gubba and Shebelle rivers (modified after Waterbury 1982).

The Nile drainage basins include from south to north: the Sobat, the Blue Nile, the Atbara, the Gash and the Barka; the latter two rivers do not at present reach the Nile and their water is dissipated in the plains of Central Sudan. The Indian Ocean drainage basins include the Gubba and the Shebelle which emanate from the Ethiopian Highlands. They have a linear southeast direction which follows the slope. In contrast, the western rivers which drain into the Nile curve around before they assume a northwest direction.

4.1. The Atbara

The Atbara is a strongly seasonal river. Its tributary sources are not far from those of the Blue Nile in the Ethiopian high plateau east and west of Lake Tana. Nearly all the water-producing part of the Atbara lies between Latitudes 12 and 15° north and Longitudes 36 and 40° east. The river does not issue from a lake and relies totally on many small tributaries swollen with water, rushing down in ravines to the two main branches, the Gangue (upper course of the Atbara) and the Setit-Tekazze, from July to October. During the dry season some of these tributaries dry up and the flow is greatly reduced. From November to January the Atbara in the plains of the Sudan becomes a trickle, and from March to May it dries up completely. Indeed, were it not for the large number of tributaries which supply the river with ample water the Atbara would not have pushed its way to the main Nile and would have fanned out in the plains of the Sudan before reaching the main Nile. This must have happened in the past during periods of lesser rains or prior to the capture of the numerous tributaries that now form the network of the river. The river would then have been like the nearby Gash which fans out in the closed Mareb–Gash Basin at the foothills of the northern Ethiopian Plateau (Fig. 1.10). The Gash disappears in the desert before it reaches the Atbara; its volume does not seem to be sufficiently adequate to carry it through the desert to an outlet of external drainage. It is significant to note here that in years of extensive rains and high flow the Gash connects with the Atbara and contributes to its flow.

The history of the Atbara has not been worked out in detail but indication that its bed was higher than today by 25 meters during the middle Pleistocene (ca 500,000 years ago) is attested by the presence of terraces along the banks of the river at this height. At that time it must have had an ample supply of water and must have reached Egypt (Shiner 1971; Marks, Peters & Van Neer 1987).

4.2. The Blue Nile

The Blue Nile Basin covers most of Ethiopia west of Longitude 40° east and between Latitudes 9 and 12° north. In addition to the sacred spring which lies to the south of Lake Tana and from which the little Abbai flows to the Lake and which is cited by most authors as the source of the river, the Blue Nile has many other sources. The following is a list of the most important of these, as well as the area of their basins in square kilometers (Hurst 1950).

River Rahad Basin	35,600
River Dinder Basin	34,700
Khor Beles Basin	15,200
Khor Dabus (Yabus) Basin	14,000
Khor Didessa Basin	25,800
Khor Fincha Basin	4370

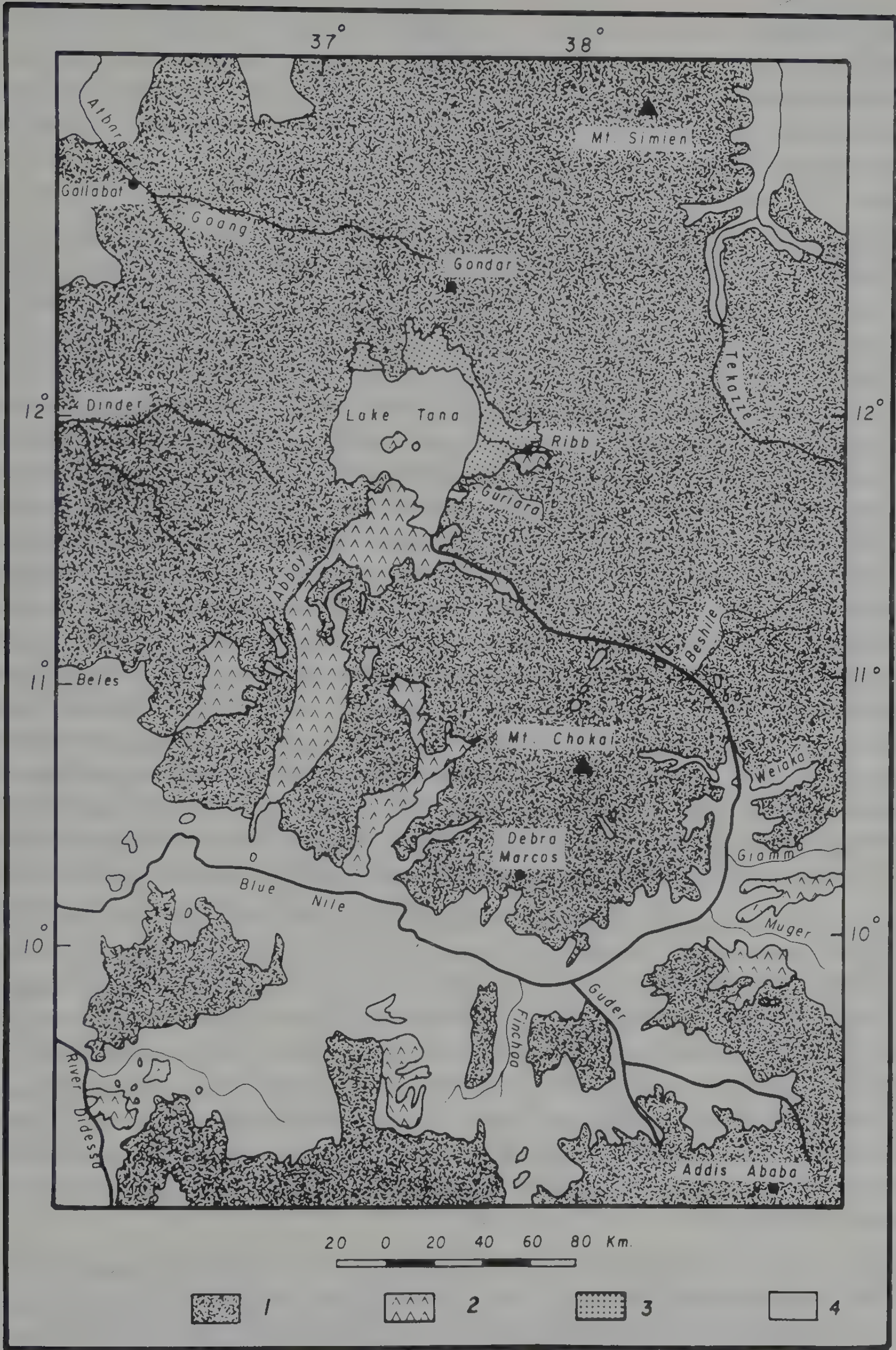

Fig. 1.11. Headwaters of the Blue Nile showing distribution of volcanic rocks; 1. trap series, 2. Aden volcanics, 3. lake deposits, 4. Nile alluvial deposits.

Khor Guder Basin	6390
Khor Muger Basin	7270
Khor Giamma Basin	19,800
Khor Beshile Basin	13,900
Lake Tana Basin	17,500
Blue Nile Basin excluding above areas	130,000
Total Blue Nile Basin	324,530

The headwaters of the Blue Nile (or Little Abbay) rise at an elevation of 1850 meters above sea level and flow north for about 96 kilometers to join Lake Tana at 1829 meters above sea level (Figs 1.10 and 1.11). Lake Tana is a shallow basin with an average depth of less than nine meters. It was formed as a result of the blocking of several of the headwater tributaries of the Blue Nile by the volcanic material which erupted intermittently from the Miocene to the Pleistocene hindering their passage. It was only in relatively recent time that these blocked waters found their way out across a narrow strait that cuts across the two islands of Debre Mariam and Shimabbo which lie at the exit of the lake. From this exit the Blue Nile (or Great Abbay) flows in a southeastern direction for 30 kilometers until the Tissisat Falls where it drops 50 meters. Below the falls the river enters a canyon which deepens progressively downstream, attaining a depth of about 1500 meters and a width of up to 30 kilometers downstream of the Debre Marcos bridge. During its descent from the falls the river flows in turn southeast, south, southwest and finally north of west around the volcanic massif of the Chokai Mountains the highest point of which is 4413 meters. Many of the west-flowing left bank tributaries of the Abbay originate in the rim of the eastern scarp not far from the tributaries of the Awash River (which forms the major drainage line of one of the Rift Valley closed basins to the east). This may be taken as an indication that many of these tributaries and indeed most of the drainage of the Chokai mountains including the Tekazze headwaters flowed east toward the Red Sea and did not form part of the Blue Nile system except when they were captured and diverted westward as a result of the earth movements related to the formation of the Rift Valley (Williams & Adamson 1982).

Between Lake Tana and the Ethiopia–Sudan border the Blue Nile descends 1300 meters in about 850 kilometers, a fall of one and a half meters in every kilometer of length. Between the border and the town of Roseires in the Sudan the river runs in a straight rock-cut channel about forty meters deep and has a flatter gradient. At Roseires and up to Khartoum, the river starts to meander and its gradient flattens greatly. It falls from an elevation of 480 meters above sea level at Roseires to 420 meters above sea level at Sennar which lies about 280 kilometers to the north. From Sennar to Khartoum the Blue Nile falls another 65 meters over a distance of 350 kilometers. The total fall in river level between the Sudan border and Khartoum is about 126 meters over a distance of about 900 kilometers, or about one meter for every seven kilometers of stretch.

As a consequence of the flattening of the gradient of the river at its proximal end the velocity of the river is reduced and its capacity to carry its load of sediment is greatly hampered, allowing a large part of this load to be deposited. The flat area between the Blue and the White Niles, known as the Gezira Plain, is the site at which these sediments accumulated layer above layer over the years, forming one of the most fertile areas of the Sudan. These sediments are the subject of intensive studies (Williams & Adamson 1982). The thickness of these sediments varies from one place to another averaging about 60 meters. Considering the enormous quantity of sediment

the river carries, this thin column of sediments is evidence of the relative recent age of the river which, as we have already pointed out, must have developed after the eruption of the young volcanics into which it is incised and after the tilting of the elevated land to the west, thus directing the course of the river toward the Nile at an even later date. Several buried channels of the Blue Nile were identified in the Gezira Plain which clearly show that the river fanned out at this plain for long periods of time (Fig. 1.8). As we shall show in a later chapter, the sediments of the Blue Nile did not reach Egypt except at a very late time (?800,000–700,000 years ago). Before that time the river seems to have fanned out or terminated in a lake. The Egyptian connection was interrupted during periods of low flow which disabled the river from pursuing its course into Egypt.

4.3. The Sobat

The area of the Sobat Basin is approximately 224,000 square kilometers. The two major tributaries of the river, the Baro and the Pibor, derive most of their waters from the Ethiopian Highlands falling rapidly into the wide plains of the Machar marshes which occupy an area of about 6500 square kilometers (Fig. 1.12). To the east of the headwaters of the Sobat lies the Omo River and the Upper Rift closed basins. The latter includes the series of lakes which extends from Lake Chamo in the south to Lake Zwai in the north (Fig. 1.5). It is likely that many of the headwater tributaries of the Sobat formed part of the drainage network of the Omo River basin prior to the formation of the Rift Valley system and the delineation of the closed modern Omo River catchment basin which became separated from the Sobat basin by a well-defined north–south divide running approximately along Longitude 36° east. This divide was frequently breached during periods of high rainfall when Lake Turkana's level rose and the Omo overflowed the divide and drained into the Nile Basin. Between 7500 and 2000 B.C. Lake Turkana, where the Omo flows, stood at 80 meters above its present surface level and fed northwestward into the Nile. Evidence of this overflow includes raised beach deposits, lake sediments and fossil fresh-water molluscs (Nyamweru 1989). Here again there is evidence that the present-day Sobat is a relatively recent river.

5

THE NUBIAN NILE; TRANSIT FROM THE INTERIOR OF AFRICA TO THE MEDITERRANEAN SEA

The swell which separates the Egyptian and Sudanese basins extends from Shabluka (85 kilometers north of Khartoum) to Aswan (Fig. 1.13). It forms the bridge across which the interior basins which derive their waters from African sources reach the Mediterranean. It is an area of bare rock cut today by a swift and youthful river obstructed by a number of cataracts and water falls. The natural river in this stretch is still adjusting its course as it wears down the cataracts which obstruct its path. It is swift, has a steep gradient and is extremely difficult to navigate. Prior to its cutting by this river the Nubian swell represented for a long time a barrier which separated the African basins from the Egyptian Nile and the Mediterranean Sea. It was only in relatively recent time that this barrier was breached. We will see in our later discussions that the connection it affected was interrupted many times.

The stretch of the Nubian Nile to the south of Aswan was converted into a vast reservoir of water after the turn of the century by the building of the Aswan dam in 1902 and then by the great Aswan High Dam completed in 1970. Before the building of the High Dam and the rise of the level of the water in this stretch, navigation was possible only during flood time when the protruding rocks of the cataracts were covered with water, and even then it was not without difficulty and great danger (Fig. 1.14). Vivid descriptions of the difficulties encountered in transporting armies and ammunition across this part of the Nile are given in the history of the expeditions which ventured into the Sudan during the nineteenth Century.

The most forbidding and desolate part is the 120-kilometer stretch of the second Cataract, called Batn el-Hagar (Arabic for Stone Belly) which extends from Wadi Halfa to Amara. Along this picturesque country the river is bound on the east by towering crystalline rocks and on the west by sand plains. Its course is obstructed by the rapids of Amara, Semna, Dal and Abka. A series of Ancient Egyptian temples dot the landscape along this stretch, the most important of these for our purpose of study are the Semna and kumma forts which are perched 123 meters above the water of the Nile. Along the cliffs of this stretch are inscribed the flood levels of the Nile in Middle Kingdom times (see discussion in Part II of this book).

From Khartoum (elevation 378 meters above sea level) to Aswan (elevation 91 meters above sea level) the Nile has a course of 1847 kilometers and a slope of one meter in every 6.5 kilometers of length. This fall is not uniform along the entire stretch of the Nubian Nile but increases greatly along the six cataract regions. The greatest fall is along the Fourth Cataract which extends for 110 kilometers from a point 97 kilometers downstream of Abu Hamad to

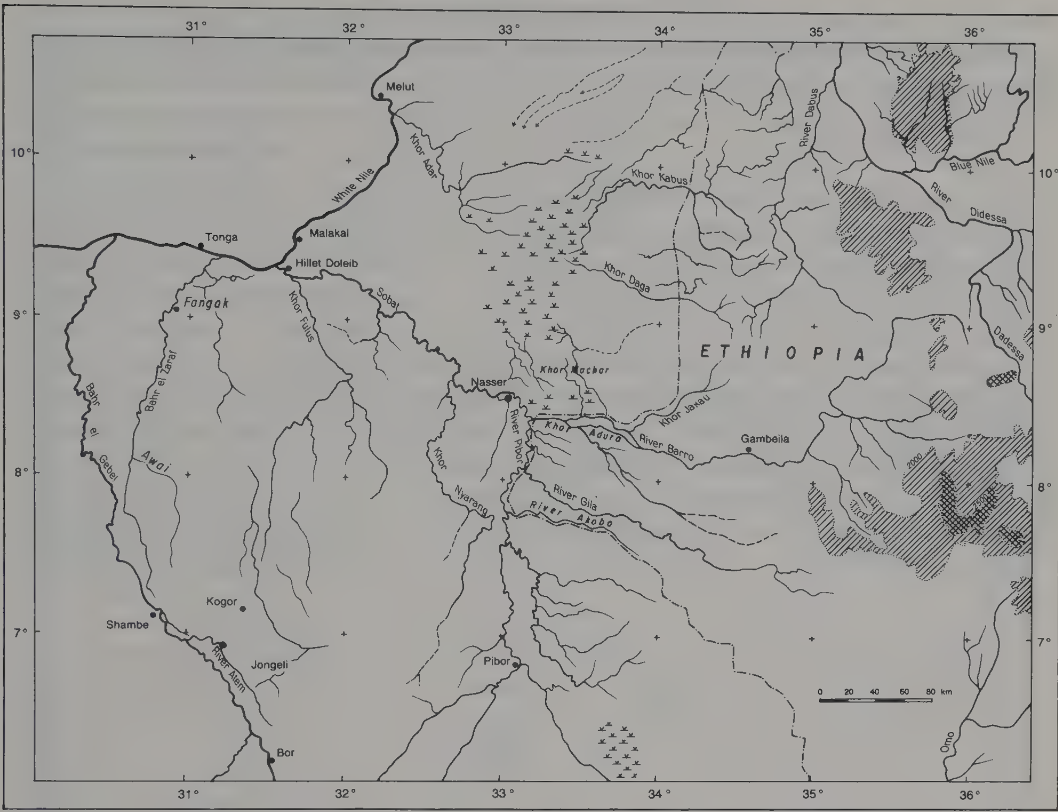

Fig. 1.12. Map of the Sobat Basin.

Kerma. Along this stetch the Nile falls from an elevation of 297 meters to 240 meters above sea level, that is at the rate of one meter for every 2.25 kilometers of stretch. Next comes the fall along the fifth Cataract which extends from Berber to Abu Hamad for a distance of 160 kilometers, in which the river falls from 361 to 306 meters above sea level, that is at the rate of one meter for every three kilometers of stretch. The second Cataract, which extends for 200 kilometers to the south of Wadi Halfa, has a similar rate of slope falling from an elevation of 194 to 128 meters. Between the fourth and fifth cataracts lies the wide alluvial plain of the Dongola Kerma stretch which extends for a distance of 313 kilometers and has the low slope of one meter for every 12 kilometers of stretch. Between the first (Aswan) and second cataracts the Nile has a length of 345 kilometers and a slope of one meter for every 12.5 kilometers. The mean width of the river is 500 meters. The river cuts across sandstone country.

The drainage of this very arid region is shown in Fig. 1.13 based on the maps of the Sudan Survey and from satellite imagery and from Pflaumbaum (1987). Today the Nubian Nile receives little if any water supply from the numerous wadis that drain into it, but there is ample evidence that in the past many of these wadis were active and carried considerable quantities of water to the Nile. Recent work in Wadi Howar (Pachur et al 1990) shows that the wadi was active episodically between 9400 and 4800 before present, with many side lakes developing

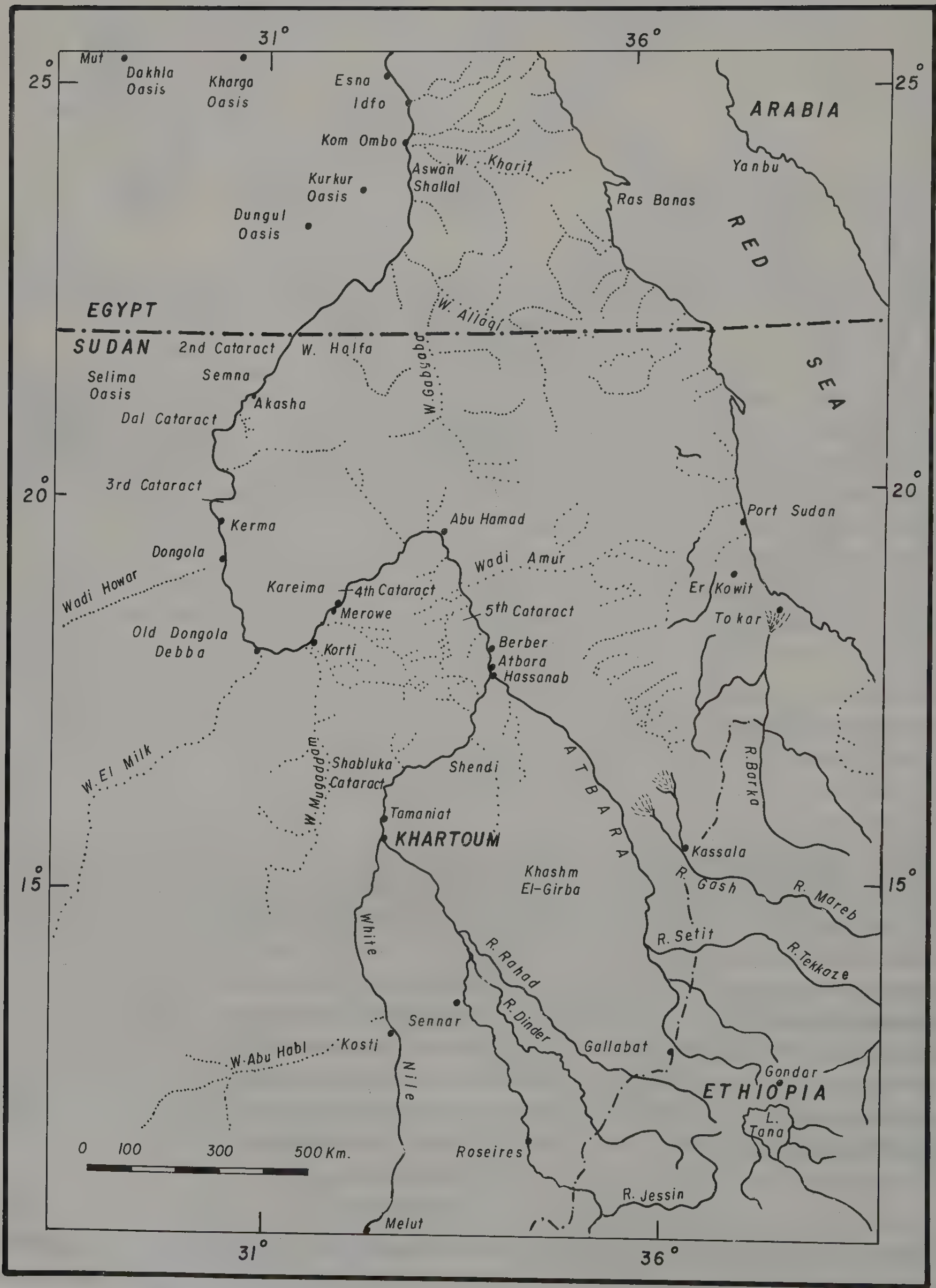

Fig. 1.13. Map of the Nubian Nile.

which contained species of fish, crocodile, hippopotamus and tortoise. The water contributed by the wadis of the Nubian massif, when it came, represented an important contribution to the flow of the Egyptian Nile. Not only was the Nubian drainage area large, but the water coming from it was not subject to great losses in swamps or bank overflows as was and is the case with the equatorial and Ethiopian sources.

The Nubian massif forms the bridge across which the Nile waters have access to the sea. Any disturbance that affects it, could affect the shape of the Nile and the quantity of water that drains to the sea. The slightest tilting of the Nubian massif would indeed sever the connection of the Egyptian Nile from its sources and could cause it to decline or even to dry up. The Shabluka gorge which begins the long journey of the Nile waters into the waste of the Sahara is in effect, a ring complex which lies on one of the great east–west transcurrent faults that traverse the Nubian Desert. Many other east–west faults traverse the Nile in this stretch. In November 1981 an earthquake occurred at one of these faults at Kalabsha. It aroused great anxiety among the authorities in Egypt as it occurred 10 years after the full operation of the Aswan High Dam. The consensus is that the quake does not seem to be related to the weight of the water column in Lake Nasser for it occurred along an east–west fault which is known to have been seismically active since its inception and up to at least Roman time (Said 1964).

Fig. 1.14. The tug at Dal Cataract (after Wallis Budge, E.A. (1907). The Egyptian Sudan, Kegan Paul, Trench, Trübner & Co., London).

6

THE EGYPTIAN NILE

The Egyptian Nile flows from Aswan to the Mediterranean with a gentle gradient ranging from one meter for every 15 kilometers of length in the Qena region to one meter for every 11.4 kilometers in the Beni Suef region. Along this stretch the river flows in a channel made up of its own sediments which were deposited year after year prior to the building of the High Dam. Past Cairo the river fans into the Damietta and the Rosetta branches of the delta. In the past the distributaries of the delta were more numerous and reached as far eastward as the Pelusiac branch which drained in Sinai, and as far westward as the Canopic branch which drained to the west of Alexandria.

As previously stated the Egyptian–Nubian Nile is unique among the rivers of the world in that it persists in its course to the Mediterranean across the arid and rainless Sahara for a distance of close to 2700 kilometers without receiving any substantial inflow of water. In this chapter I shall attempt to explain the unique and exceptional conditions that allowed the river to pursue its course in the waste of the Sahara rather than terminating it and fanning out into an interior delta before entering Egypt or reaching the Mediterranean. The wondrous river is truly a geological freak.

The history of the Egyptian Nile is complex and its reconstruction is difficult. It is inferred from the study of the relics it has left behind. Its former course and height can be surmised from an examination of the platforms and terraces that were left behind by the former rivers. The study of the sediments it deposited in its past channels and floodplain, their elevation, disposition, composition, and fossil as well as archeological content helps in reconstructing the environments and the physical conditions under which they were formed and the sources from which they were derived. It is to be expected that not all the features and sediments which the river left behind during its successive stages of development would be preserved or would be amenable to direct examination. Some of the exposed sediments, for example, could have been washed away by later rains without leaving a trace; some of the buried sediments may not be accessible for study. In the case of the Egyptian Nile enough data concerning its buried sediments is now available from a large number of boreholes drilled in the valley and delta after the search for water and oil. Many of these wells penetrated the entire column of riverine sediments thus completing the picture obtained by surface mapping of the exposed sediments and giving a reasonably complete record of the history of the river.

One of the difficulties encountered in the study of the history of the Egyptian Nile is the fact that its sediments cannot be dated in absolute terms. With the exception of the youngest of them

they are barren of materials that could be given an absolute age by radiometric dating methods. There are no intervening datable rocks within the column of sediments of the Nile which could help build a time reference scale to which other events could be related. In this respect the Nile differs from East Africa and the Levant where the events are dated in reference to a scale of absolute chronology based on the radiometric age dating of the numerous intermittent outpourings of the volcanic rocks which occurred in the recent past. The dates given in this book to the events of the river are, therefore, relative and are based on correlations with other events.(1)

Throughout most of its geological history the land of Egypt was inundated by a sea that invaded it intermittently from the north. The maximum inundation occurred some 60 million years ago when it covered almost all the land of Egypt and a good part of Northern Sudan. From that time on the sea started to retreat almost without interruption until, some 30 million years later, the sea shore was in the neighborhood of Fayum and Siwa Oasis, and some 20 million years later the shore line was close to its present position. During the period of the sea retreat the newly elevated land of Egypt developed a drainage network which occasionally terminated in the Fayum or the eastern tip of the Qattara depression, forming great deltas the sediments of which are preserved around the shores of Lakes Qarun (Fayum) and Moghra (Fig. 1.15). The sediments of these fossil deltas are shallow and preserve many interesting vertebrate remains including some of the oldest known fossil hominid apes. Apart from the preserved deltas of these old drainage systems, there is hardly any trace of the channels of the rivers of these old drainage systems which terminated into these deltas. The sediments which these rivers must have left behind seem to have been of small thickness and must have been destroyed totally by later erosion. The rivers did not seem to have incised deep channels and must have been shallow and meandering laterally over the exposed surface of Egypt.

In contrast to these old defunct rivers the Nile incised a deep gorge in the structurally depressed area of its present-day valley. This deep gorge was later filled with sediments of the estuaries and numerous rivers which occupied it.

Figure 1.16 shows longitudinal and transverse sections of the delta of the Nile constructed from data obtained from the logs of some of the deep wells drilled after the search for oil. The figure shows the structure and configuration of the substratum upon which the riverine deposits of the Nile and its ancestors accumulated and also the extent, nature and thickness of the successive layers of these riverine deposits. As shown in the figure, the substratum which received the first of the Nile sediments was not flat. The northern part of the delta up to the latitude of Tanta was low and formed an embayment of the Mediterranean which remained under

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(1) Absolute dates were only used in the case of the younger sediments where radiocarbon dating technique was used. This is a technique of absolute dating based on measuring the amount of decay of the radiocarbon (^{14}C) in plant or organic material after death and loss of contact with the atmosphere. Since the half-time life is short the practical limit for using the technique to date samples is about 60,000 years at most. Since the activity of ^{14}C in the atmosphere has not been constant throughout time the dates are usually adjusted against calibration curves which have been worked out by numerous authors. None of these curves is perfect although "high precision" curves based on $^{14}C/^{12}C$ ratio in tree-ring dated wood are the best at present. For the sake of simplicity tree-ring-calibrated years are taken as equal to calendric years and are designated B.C. in this book. All other radiocarbon dates, and in particular those made before the formulation of the advanced calibrated curves, are designated before present (B.P.). These dates are not as accurate as one would hope. They, however, give approximate dates for the events.

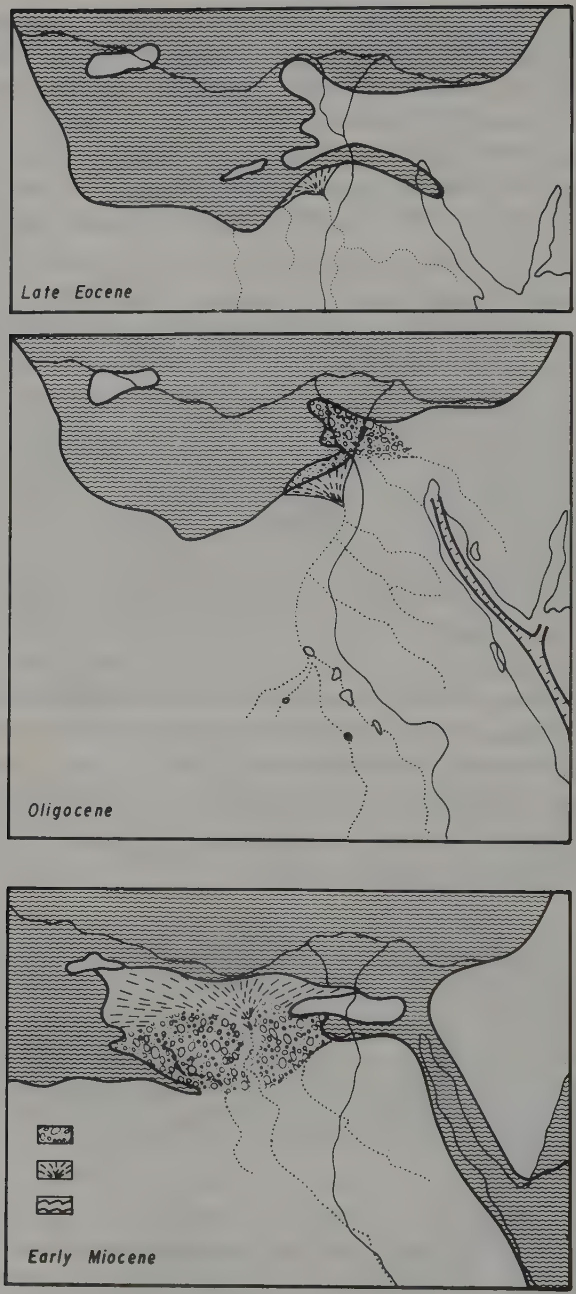

Fig. 1.15. Map illustrating hypothetical drainage of the elevated land of Egypt during the late Eocene, Oligocene and early Miocene time; 1. river deposits, 2. deltaic deposits, 3. ancient seas.

the waters of that sea until the Nile started bringing in its sediments. The pre-Nile surface in this embayment is made up of marine muds that were deposited in the open Mediterranean sea prior to their being covered by the deposits of the river.

The southern part of the delta was high. At the time of the oncoming of the first waters of the Nile it was a land mass that was not covered by the sea. Its southern border formed a great cliff which towered over the south and west sides of the submerged northern embayment. In fact, the Southern Delta Block formed a lofty plateau of limestone topped by extensive basalt sheets which had been spewed by volcanoes that were active some 10 to 20 million years earlier. This plateau must have looked very much like the horizontally-disposed limestone table lands of modern northern Egypt and must have stood at a height of more than 1000 meters above the floor of the North Delta Embayment.

When the Nile first broke in, it started by incising its course in the South Delta Block and pouring its sediments into the North Delta Embayment. It is in the North Delta Embayment, therefore, that one can find the maximum thickness of the column of sediments of the Nile, for the South Delta Block was the site of downcutting in the earliest phases of the river. It did not start to receive sediments and build up its own bed except after the Embayment had been filled up. Figure 1.16 shows that the column of sediments of the Nile in the Embayment is more than four kilometers in thickness.

The column of Nile sediments which accumulated in the expanding delta has been recently penetrated by the numerous boreholes drilled after the search for oil. A close look at the logs of these boreholes shows that the column of river sediments left behind is made up of many layers which can be grouped into a number of units, which differ from one another with regard to their composition and texture. Each unit of these seems to have been deposited under a unique set of conditions reflecting the changes that must have taken place in the nature and sources of the river with time. We can distinguish at least five successive units of riverine sediments separated from one another by episodes in which river sedimentation ceased. These units must

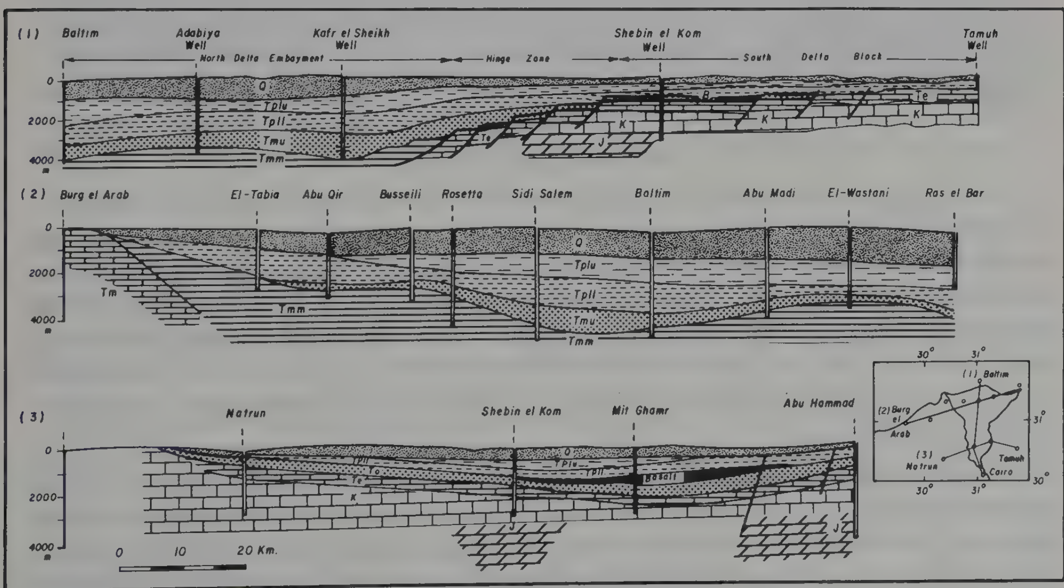

Fig. 1.16. Longitudinal and cross sections across the delta. J. Jurassic, K. Cretaceous, Te. Eocene, To. Oligocene, B. basalt sheets, Tpll. Gulf phase marine deposits, Tplu. Paleonile deposits, Q. Prenile and Neonile deposits (after Said, 1981).

have been deposited by different rivers. The oldest three units were deposited by rivers which seem to have been of local derivation with sources in Egypt and possibly, at least in the case of one river, in Africa, although the evidence here is not conclusive. The younger two sets were deposited by rivers that had established an African connection for the first time. The older of these rivers, the Prenile, was a competent stream with an enduring African connection. The younger of these rivers, the Neonile, was a considerably less vigorous stream with tenuous African connections; at times it reached Egypt with a copious supply of water, at others it stopped flowing into it or came with a lesser supply of water.

In the following paragraphs we shall deal with the different rivers which occupied the Nile and its delta, under the following headings: 6.1: The Early Egyptian Niles, from a deep canyon to a graded river; 6.2: The Prenile, an African connection is established; 6.3: The Neonile, the African connection becomes tenuous.

6.1. The Early Egyptian Niles, From a Deep Canyon to a Graded River

The Egyptian Nile owes its origin to a unique event which occurred some 7 to 6 million years ago when the Mediterranean Sea, which is connected to the world oceanic system only by the narrow Strait of Gibralter, was severed from the ocean and started to dessicate. This remarkable event, which was caused by an earth movement which raised the dike beneath the Strait of Gibralter above the Atlantic sea level, led to the conversion of the Mediterranean Sea into a great lake. Lying in a region with a high rate of evaporation and little river discharge, the sea started to shrink and finally to desiccate; its bottom was covered with an immense layer of halite, gypsum and other salts resulting from the evaporation of its waters. We owe this remarkable discovery to the work of the Deep Sea Drilling Project, an international program for the study of the ocean floor. In its leg in the Mediterranean Sea in 1972 several boreholes were drilled at the bottom of the sea to tap the successive layers of sediments accumulated during its past history. The study of these sediments revealed the presence of a consistent and thick bed of evaporites beneath the bottom of the sea which was dated as of late Miocene age (ca. 7 to 6 million years ago). These evaporites were interpreted as having been formed in a series of shallow saline lakes representing the relics of a desiccating and shrinking sea.

The lowering of the Mediterranean sea level and its final desiccation must have affected the evolution of the landscape of the surrounding regions. It must have caused, among other things, the deepening of the river channels draining into that sea in order that they may adjust to its new level. Channels cutting deep into the newly elevated north African and south European plateaus are recorded from Libya, southern France and Egypt. None of these channels can be seen on the surface today for they are hidden under the mass of sediment which has filled their channels since the time of their formation; their recognition is only possible through geophysical methods or through drilling.

The collected water vapor resulting from the drying of the Mediterranean moved to the land causing heavy outpourings of rain all year round along the high and newly elevated mountain ranges of the Eastern Desert of Egypt. The wadis through which these rains were channeled incised deep gorges in these mountains which were then considerably higher than today. They collected and fed the trunk channel of the ancestral Nile, the *Eonile*, which occupied a structurally controlled path in the basinal area between the Eastern Desert mountain ranges and the Western Desert plateaus (Fig. 1.17). Many of the wadis which fed this early Nile system from

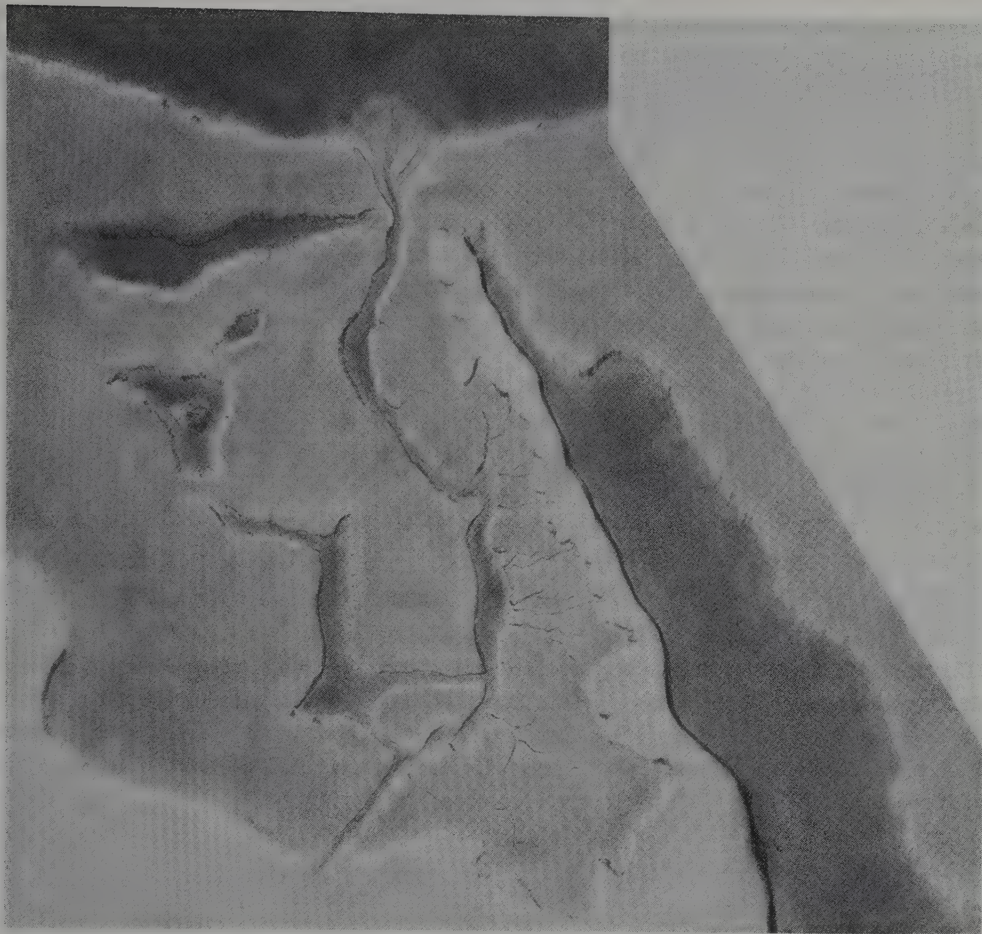

Fig. 1.17. Sketch showing the Eonile canyon.

the Eastern Desert can be still seen today in the form of numerous dry wadis which dissect the great mountain masses of the Red Sea Hills. Evidence at hand shows that the Eonile was fed by local rains; the sediments it carried were all derived from rocks that then covered the surface of Egypt. For a detailed discussion on the subject of the early Niles the reader is referred to Said (1981).

The wadis of the subdued plateau of the Western Desert which fed this ancestral river were all obliterated as they were covered under the mass of sand which swept the large fetches of that desert during the arid phases which followed. Some of these have been recently delineated by the use of Shuttle Imaging Radar (SIR) and have been assumed to have great depth and large size (McCauley et al 1982, 1986; Issawi & McCauley 1992). Without intensive geophysical work, however, the exact path and depth of these wadis can only be inferred. It is also possible that the elongate great depressions of that desert mark the position of the trunk channels of that old drainage system. The origin of the large number of depressions which are now occupied by the lush oases or the barren Qattara has been the subject of great speculation and controversy.

Many authors believe that they were deflated by wind, but others recognize that it is almost inconceivable for wind to remove and deflate the hard limestone cap rocks into which these depressions were excavated. For many authors the depressions seem to have been formed by rain as it soaked into the somewhat flat limestone beds of the middle and northern latitudes of that desert dissolving the limestone and causing the development of sink holes, caves and other solution features (Stringfield, Lamoreaux & Legrand 1974; Said 1983; Albritton, Brooks, Issawi & Swedan 1990). This led to the final disintegration of the rock mass and the massive collapse of the roof. The resulting debris and waste material was ultimately blown away by wind during the arid intervals or removed and transported by running water during the wet intervals. The channels that drained these depressions into the greatly lowered Nile have been identified only recently, for they were all buried under later fill. One of these buried channels was discovered in Nubia across the arch which separates the oases depressions from the Nile (Haynes 1980). The discovery of this channel shows that these depressions, at a certain stage of their history, had an external drainage and an ultimate access to the sea, thus giving credence to the idea that the depressions were the result of water action. Prior to the discovery of this and other access channels wind was the only agent that could explain the formation and excavation of interiorly-drained depressions. It is now possible to consider the depressions as segments of old streams dismembered by karstic processes during the late Miocene, and afterwards modified by wind and river action.

As the Mediterranean sea level fell, the Nile bed was eroded and deepened to respond to this new level. This early Neonile formed a deep canyon the bottom of which reached depths well below the present-day sea level. Borehole data as well as seismic and gravity data show that the Eonile had a depth of 170 meters at Aswan, 800 meters at Assiut, 2500 meters north of Cairo and more than 4000 meters below sea level in the northern reaches of the delta. The gradient of the Eonile averaged about 1 : 1700 as compared to that of the modern Nile which is about 1 : 12,000. Indeed the river at that time "formed a canyon deeper, longer and just as awe-inspiring as the well-known Grand Canyon in Arizona". Figure 1.18 shows the gradient of the channel which was cut by the Eonile and shows that it was already marked by numerous highs and lows that represented falls, constrictions or deeps in its path. Among the prominent highs are the cliffs facing the North Delta Embayment, the waterfalls at Cairo, north Minia, Gebel Silsila (to the north of Kom Ombo) and many other places in Nubia. The area around Tahta was a considerable low.

The sediments which the swift Eonile carried to the sea were coarse materials derived from the mountains of Egypt. They were deposited in the form of fans in front of the river mouth (or mouths) at its confluence with the sea. These fans are buried underneath the surface and are recognized only in the boreholes of the north delta reaches at depths ranging from 3500 to 4000 meters. The average thickness of these sediments is 700 meters or close to one fifth of the total sedimentary column deposited by the rivers which occupied the valley from the time of its inception (Fig. 1.32). The Eonile was indeed an extremely vigorous river dumping an estimated 7000 cubic kilometers of sediment in less than two million years.

The shape and dimensions of the Eonile canyon must have resembled, to a great extent, the Grand Canyon of the Colorado River, Arizona, although the Eonile Canyon seems to have been longer and deeper. The Eonile Canyon had approximately the same width as the Colorado Canyon. Both rivers cut their paths in bare horizontally-disposed sedimentary strata varying in

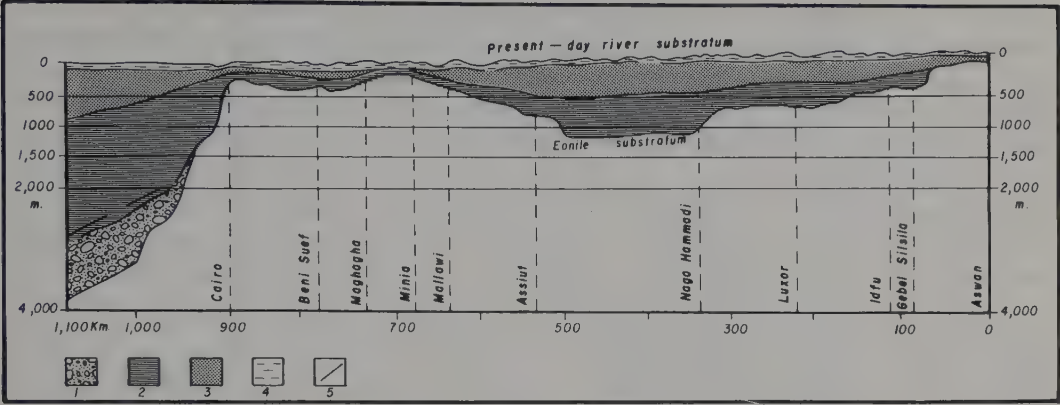

Fig. 1.18. Longitudinal section from Aswan to the Mediterranean showing Nile substratum: 1. Eonile deposits, 2. Gulf phase and Paleonile deposits, 3. Prenile deposits, 4. Neonile deposits, 5. salt beds.

lithology and color. Both deepened their channels in strata of different composition in response to a lowered base level. The Eonile Canyon was cut in a very short time during the late Miocene, while the Grand Canyon has been forming since the early Miocene and up to the present. The Eonile was a small river in comparison to the Colorado River. The Colorado and the modern Nile are comparable; both cross large stretches of desert country but receive sufficient waters from sources beyond to carry them through successfully.

As in other parts of the Mediterranean the Eonile sediments are capped and, in many cases, intercalated with salt and anhydrite beds which formed during the final stages of desiccation of the sea. These beds form a distinctive marker in all the wells drilled in the North Delta Embayment.

With the advent of the Pliocene some 5.4 million years ago, the Mediterranean Sea resumed its connection with the world's oceanic system and started to fill up, with the result that the deep Eonile Canyon was transgressed by the advancing waters of the sea and transformed into a narrow and long gulf which spilled over the adjacent parts of the delta (Fig. 1.19). Detailed mapping of the boundaries of this gulf shows that its average width was about 12 kilometers except where the gulf had extended into the mouths of the wadis which drained into the Eonile forming arms the longest of which was about 30 kilometers (Little 1936). The gulf extended as far south as Aswan where, to the surprise of everyone, its sediments were recognized in one of the boreholes drilled at the site of the High Dam. The site of the Dam was thought to be underlain by granite rock as was the case with the earlier Aswan Dam. In fact, the site was on an earlier bed of the Nile. The Pliocene gulf deposits were recognized at a depth of 170 meters below the surface (Chumakov 1967).

At first, the gulf was filled with marine waters but soon it was converted into a brackish estuary and finally into a veritable river, the Paleonile. The sources of this river are not known with certainty. The lithology and mineral composition of the sediments of this river are uniform, and their source must be sought in areas receiving sufficient precipitation. The fact that the Paleonile sediments are made up of fine-grained muds and are completely lacking in coarse

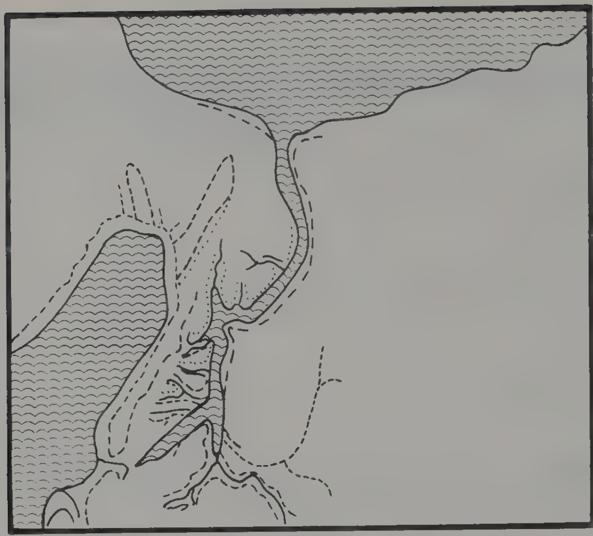

Fig. 1.19. Paleogeography of the Nile in Egypt during the Pliocene (Gulf Phase).

materials suggests strongly that the sources of the river were in a terrain with an effective vegetation cover. The rains must have been considerable and distributed fairly evenly over the year to allow for this uniform column of fine-grained sediments to form. The vegetative cover must have been thick. Intense weathering caused the chemical disintegration of the subsoil and the slipping of its fine products into the Nile, filling it with fine-grained muds. Judging from the large thickness of these sediments, which reach about 1.5 kilometers in the delta region, this period must have lasted for a long time, probably in the range of 2 million years.

The scanty work carried out on the faunal remains included in the Paleonile sediments shows that they do not belong to the Central African fresh water faunal assemblage. This suggests that the river must have had its sources in Egypt, probably in the highlands of the Eastern Desert and Nubia. Proof that the Paleonile received sizeable amounts of its water from the numerous wadis of the Red Sea hills is provided by the sediments of this river which fringe many of the wadis that drained these hills. Our current opinion about the origin of the Paleonile may change if future paleontological work proves the presence of Central African faunal elements in its sediments. Judging from the lithology and texture of these sediments, it is possible to conceive the Lake Sudd as a possible source. A Central African connection may have come as early as the late Pliocene.

The sediments of the two rivers, the Eonile and the Paleonile, and the intervening Gulf phase filled the canyon and gave it a gradient similar to its present-day gradient. They represent more than 70 percent of the total amount of riverine sediment that has been carried by the Nile since its start (Figs 1.16 and 1.18).

The beginning of the Pleistocene (2 to 1.8 million years ago) saw an arid episode in Egypt. Not only did the rains stop but the Nile itself ceased to exist; Egypt became a veritable desert. The vegetation that had covered the land was totally destroyed. Winds swept the desert converting it into a dust bowl from which the eroded topsoil of the fallow land was swept away.

The surface became bare rock or was covered with large cobbles of the durable mineral quartz. During this long period of hyperaridity, which probably lasted for one million years, two short episodes of frequent rains interrupted it. The first episode fed a competent but ephemeral river, the Protonile, which carried a load of sediment consisting mainly of coarse sands, gravels and cobbles which were derived from the bare surface of the land which had developed during the earlier arid period. The sediments of this river form terraces along the banks of the modern river from Nubia to the Mediterranean; its sources seemed to have been totally in Egypt and Nubia. In Idfu the terraces of the Protonile form the wide Darb el-Gallaba plain (Fig. 1.20) which has an elevation of some 35 to 40 meters above the modern floodplain. The wide Darb el-Gallaba plain (Fig. 1.20) is strewn with cobbles and gravels of this river.

The second episode of frequent rainfalls which interrupted this long period of hyperaridity was one which left alluvial fans along the mouths of the wadis which drained the high mountains of Egypt into the Nile. There is no indication that this phase developed into a flowing river. The importance of this short wet episode, called Armantian, stems from the fact that its deposits include the earliest artifacts that could be related to humans in the Egyptian Nile Valley (Biberson, Coque & Debono 1970). The fact that the Armantian fans look very much similar to those accumulating along the mouths of the wadis today after the winter cloudbursts leads one to believe that the Armantian rains were also of similar nature and seasonality. This is the earliest time known in which Egypt became subject to a climatic pattern somewhat similar to that of today.

A break-through in the history of the Nile occurred when an African connection was established. Between the time when the Nile started excavating its canyon some 6 million years ago and the time it started establishing this connection some 800,000 to 700,000 years ago the climate of Egypt was totally different from the one prevailing today. Three times during this early period the country had intense rains capable of sustaining highly competent rivers with great erosive power. Although it is difficult to decipher the pattern or the quantity of the rains of these episodes, it seems that the period when the Paleonile flowed was the wettest.

6.2. The Prenile, An African Connection is Established

With the advent of the middle Pleistocene some 800,000 to 700,000 years ago a mighty river with a distant source reached Egypt. This river, the Prenile, drew its waters from Ethiopia when the Atbara and possibly the Blue Nile pushed their way into Egypt across the Nubian swell by a series of cataracts. This event must have been instigated by the earth movements which affected the Ethiopian Highlands and brought the Main Ethiopian Rift (Fig. 1.10) and the present-day relief of Ethiopia to their modern shape. This resulted, as we have seen, in the tilting of the land and the directing of a large part of the drainage of the Ethiopian Highlands and the Red Sea range toward the Nile Basin rather than the Red Sea as must have been the case before.

During that time the flat basin of the Sudd region must have been overwhelmed by the flow of the rivers which were directed toward it. It must have grown in size to an enormous lake which seemed to have overflown its banks into the Omo River basin. Intense earth movements seem to have affected the western African rift reversing part of the Congo basin drainage into the incipient Lake Victoria and causing it to assume a larger area than at present (Fig. 1.7). It is indeed possible that Lake Victoria, which was probably formed at that time, overflowed its northern shores and contributed to the Sudd area or even to the new river of Egypt. Evidence

at hand is not conclusive in this respect; no borehole has been drilled deep enough to reach the earlier sediments of the lake, and though the mineralogy and composition of the Prenile sediments in Egypt point to a clear Ethiopian connection, they do not bar an Equatorial Lake connection. The presence of an extant molluscan fauna of definite African origin in the sediments of the Prenile clearly points to an Ethiopian connection.

The following table of events (Fig. 1.21) summarizes the developmental history of the Nile since it established an African connection, and gives the archeology and the climatic events that characterized this period.(2)

The Prenile was the first river to develop an African connection. It was a vigorous and competent river with a copious supply of water which was sustained for close to 400,000 years. It carried an enormous quantity of sands that were deposited on its large floodplain and delta, both of which exceeded in extent those of the modern Nile. Its sediments are coarse, massive and thick. Toward the top they are intercalated with dune sands indicating that arid conditions must have prevailed in the later phases of the river. They crop out in a most conspicuous way along the banks of the Egyptian Nile Valley and the delta margins, forming an important element in the landscape of the valley. They provide the source of sand for building in Cairo and all the towns of Egypt. Sand quarries in these deposits dot the valley everywhere. Indeed it can be safely said that the Prenile was the largest and most effective river in outlining the landscape of the modern valley. Even in the flat delta region the Prenile sands jut out in many places above the modern agricultural silt layer and form low mounds, the so-called "turtle backs", which played an important role in the settlement history of the marshy lands of the delta.

The Prenile sediments also form part of the fill of the modern valley and delta where they appear consistently on the logs of the wells drilled in these reaches below the famed agricultural silt layer of the Nile Valley. Since the Prenile coarse sands lie above the impermeable clay layers of the earlier Paleonile, they are capable of holding water in their pore space; the Prenile sands constitute the groundwater reservoir of the valley *par excellence.*

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(2)The events shown in the table are dated relative to a standard chronology based on: (i) The amount of declination of the earth's magnetic field which reverses from time to time. This scale is based on measuring the declination of magnetic grains in deep sea sediments which are aligned with the magnetic field soon after they are deposited. The reversals of the earth's magnetic field are recorded in the magnetic grains in the deep sea sediments. These magnetic field reversals affect the entire globe and occur very quickly. Thus they provide a synchronous, global stratigraphic horizon. The intervals of uniform magnetic field are called magnetic chrons and are numbered and, in the case of the younger chrons, are also named. (ii) The oxygen isotope stratigraphy which is based on measuring the proportions of the two primary isotopes of oxygen ^{16}O and ^{18}O in microfossils separated from deep sea sediments. The stratigraphy is based on the fact that the oxygen isotopic composition of seawater changes with time and that micro-organisms living in the sea incorporate the two primary isotopes of oxygen, ^{16}O and ^{18}O, in proportion to their abundance in seawater. Changes in the temperature of seawater cause microfossils to secrete skeletal material of different isotopic compositions. The proportion of the heavier isotope of oxygen incorporated is greater at lower temperatures than at higher temperatures. Because the proportion of the heavy isotope ^{18}O is so small the results are generally reported as differences in comparison with a standard; the lower it is the colder temperature it indicates. This made possible the identification of the glacial and interglacial ages of the past and the development of a temperature curve that suggested that the temperature difference between glacials and interglacials was about 8 degrees celsius. On the curve the glacials are given even numbers.

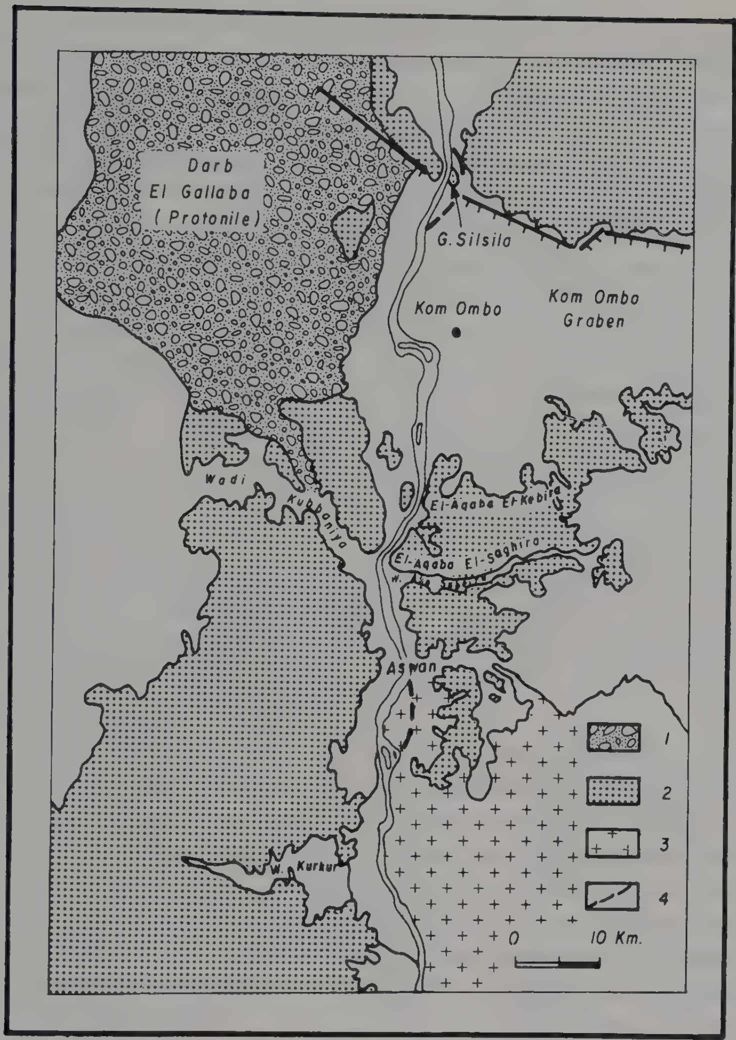

Fig. 1.20. The Kom Ombo and Darb el-Gallaba Plains: 1. gravel (Protonile deposits), 2. sandstone bedrock (mostly of Cretaceous age), 3. Precambrian crystalline rocks, 4. old Nile channels.

The Prenile sediments reach great thicknesses averaging between 70 meters in the valley and between 300 to 400 meters in the delta. Thicknesses of as much as 250 to 1000 meters are recorded from the valley and the northeastern part of the delta respectively. The greatest thickness of the Prenile sediments in the valley lies in the wells drilled to the west of the modern channel and especially in the Minia reach, and it is in this western channel that the main stream seems to have run. The surface mapping of the deposits of this river confirms the conclusion that the Prenile occupied a course which lay at the western edge of the modern valley and that the present course of Bahr Yussef ran to its east (Fig. 1.26). In the delta region, however, the Prenile sediments appear quite conspicuously in the eastern reaches of the modern Nile delta where the main flow seems to have been directed as was the case with the earlier rivers.

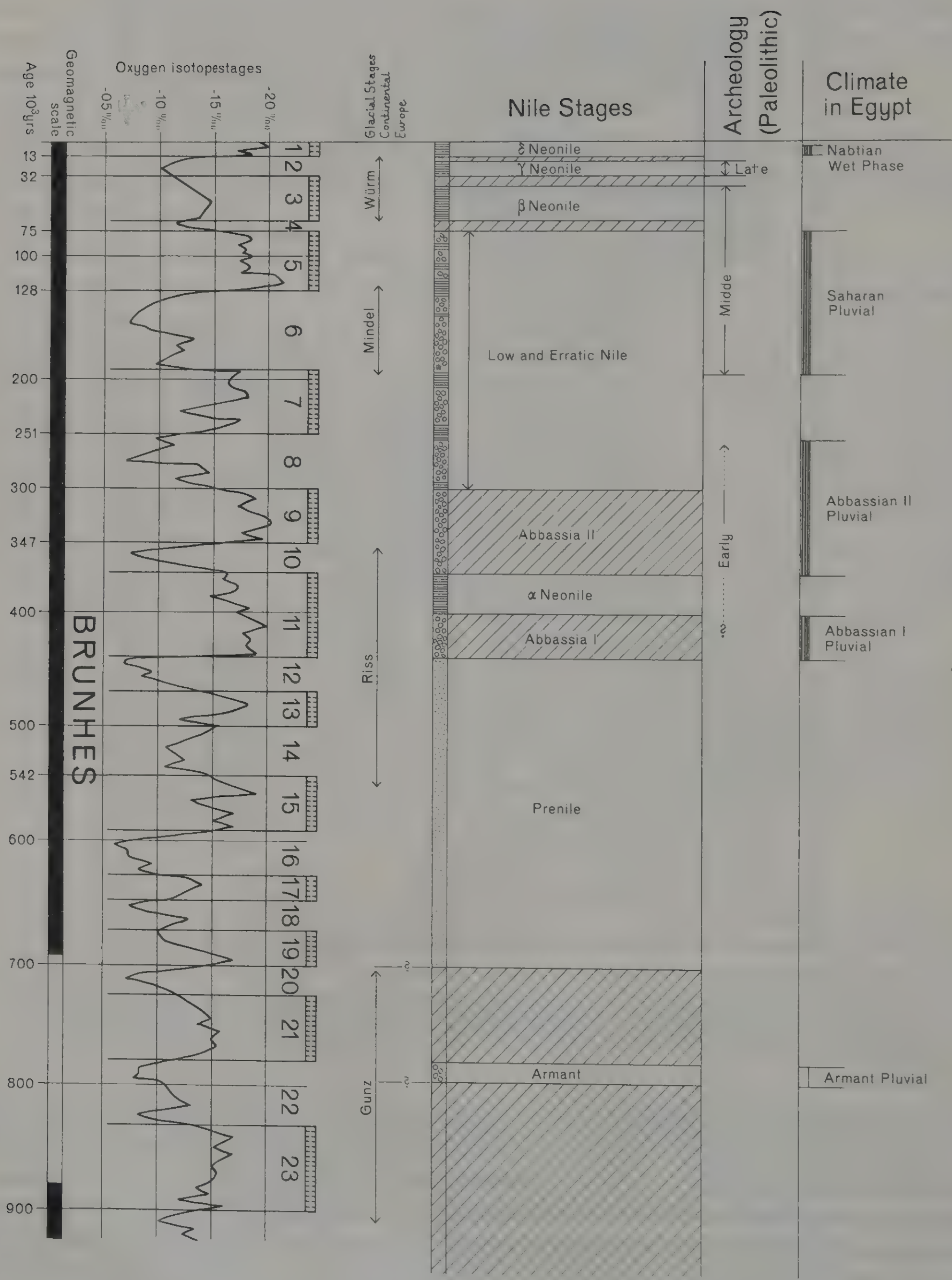

Fig. 1.21. Table showing the climate, archeology and estimated ages of the different Nile stages. Hachured areas indicate intervals of incision or deposition by ephemeral rivers.

The Prenile delta extended well into the Mediterranean and had an area at least three times as large as the modern delta. The Eastern Mediterranean Leg of the Deep Sea Drilling Project records sediments in the offshore Nile cone, some 150 kilometers from the modern shore-line, which are interpreted as belonging to the Prenile. The extent and thickness of the deposits of the Prenile make it certain that this was indeed a vigorous river depositing an estimated one hundred million cubic meters of sediment every year for the duration of its life, estimated to be between 300,000 and 400,000 years. This is indeed an enormous quantity of sediment. It amounts to more than double the quantity of sediment carried by the modern Nile. This can be attributed, in part, to the great erosive power of the youthful, swift and steep-sloping river both in Ethiopia and in Nubia. In both places the river left no deposits except rock cut platforms indicating that it was incising its course and transporting the materials it eroded from both Ethiopia and Nubia into Egypt. A good portion of the sand of the Prenile deposits seems to have come from Nubia which is mostly covered by the friable sandstones of the famous Nubian Sandstone Formation.

The accumulation of layer upon layer of the thick column of sediments of the Prenile must have taken place during a period of rising sea level when the river, in response to this rising level of the sea, aggraded and built up its bed. Such a period did occur in the Eastern Mediterranean between one million and 500,000 years ago as the climatic curve prepared by Cita et al (1972) indicates. It was a period of almost continuous rise in the sea level inspite of the fact that it was interrupted by the Gunz and Mindel glaciations of continental Europe. These glacials which are usually accompanied by a lowering of sea level did not seem to have had an effect on the eastern Mediterranean Sea.

The duration of the Prenile is difficult to assess for its sediments include no datable materials. The only fossils they carry are some extant fresh-water molluscs of African affinities which have a wide age range and are thus of no help in dating the sediments. The sediments, however, lie below a horizon which carries an abundance of fresh human artifacts of lower Paleolithic (Acheulian) age. The Acheulian is a period which had a wide time range in Africa extending from 1,200,000 to 200,000 years ago. In Egypt the artifacts are of the evolved type and are estimated to have an age of about 350,000 to 400,000 years ago. Since this horizon is separated from the Prenile sediments by several intervening events, it is likely that the river ceased to flow some 400,000 to 450,000 years ago.

6.3. The Neonile, The African Connection Becomes Tenuous

Following the cessation of the Prenile the river's connection with the Ethiopian Highlands and indeed with its African sources became tenuous and sporadic. During that long period from 400,000 years ago to the present, there occurred great climatic fluctuations which affected the headwaters of the Nile and the climates of Egypt and northern Sudan. These fluctuations will be dealt with in more detail in section 8 of this part of the book. Rivers with an African connection became incidental and far in between; they flowed into Egypt when the connection was established and they stopped flowing when that connection was severed. When they came they were vibrant at times and low at most other times; they never had the competence or length of duration of the Prenile. All the rivers with African connection carried a load of sediments similar to that of the present-day river with regard to texture and composition. Although the rivers differed from one another in regimen and the amount of water they carried their sediments are

so similar in aspect that these rivers are all grouped with the modern river as representing several generations of the modern or Neonile.

The African connection was obviously a function of the amount of rainfall on the headwaters of the Nile; but it was also affected by the tectonic activity of the Nubian massif, that unstable and flimsy bridge across which Egypt is connected to Africa. That bridge is not aseismic; it has witnessed tectonic disturbances in the recent past especially along the great east–west faults which extend for hundreds of kilometers across the river and which have been active up to very recent time. The slightest tilting of the Nubian massif could indeed sever the connection of the Egyptian Nile from its sources, causing it to decline or even dry up.

Four sets of events can be distinguished in the evolution of the Neonile (Fig. 1.21). The oldest of these was associated with the Early Paleolithic wet interval (the Abbassian Pluvial) when the African connection was severed and ephemeral rivers fed by local rains filled the Egyptian valley of the Nile. The pluvial seems to have been interrupted by a short arid episode in which the Egyptian Nile resumed its connection with Ethiopia bringing about a river, the Dandara (alpha Neonile), which was totally different from the Prenile; its sediments were fine-grained. It had a regimen which has become the pattern of all the Neonile rivers with an African connection.

The second set of events was associated with the succeeding pluvial, the Saharan. During this wet interval local winter rains supplemented a low and erratic river with an African connection. This interval saw the appearance and spread of Middle Paleolithic man in Egypt.

The Abbassian and Saharan pluvials are correlated with the Riss and Mindel glaciations of Europe which seem to have affected the distribution of the meteorological gradients, causing a change in the precipitation patterns over the African continent. The headwaters of the Nile were adversely affected and the zone of Mediterranean rains of northern Egypt extended southward bringing copious winter rains to southern Egypt and Nubia. A climatic reconstruction of this period is given in section 8 of this part of the book.

The third set of events began some 70,000 years ago and lasted for the duration of the last glacial age when two rivers with an Ethiopian connection arrived to Egypt. They carried and deposited on their flood plains in Nubia and southern Egypt great quantities of silt. These early rivers were essentially formed under similar conditions and had similar regimen and sources. Evidence at hand shows that they drew their water from the Ethiopian Highlands; the equatorial lake Plateau received lesser rainfall and Egypt was arid. They were separated from each other by a short epsiode of downcutting. The rivers were seasonal in nature approximating in their regimen the river Atbara which rises in pulses during flood time and almost dries up during the dry season.

The fourth set of events began some 10,000 years ago after the retreat of the ice of the last glacial with the advent of a river which is still extant. The silts which it carried from its sources in the Equatorial and Ethiopian Highlands were deposited in the flood plain of the entire stretch of the river in southern as well as in northern Egypt. This newest river was formed during a wet interval, the so-called Holocene (Nabtian) Wet Phase, which accompanied the retreat of the ice of the last glacial. This phase increased the flow of the river and enlarged its catchment area allowing it to flow all year round. The Nile we know today is indeed the child of that phase.

Figure 1.22 is a diagrammatic cross-section of the river in upper Egypt showing the disposition of the terraces and deposits of the successive rivers of this critical period and also the succession of strata deposited in the local wadis by the locally-fed ephemeral streams.

6.3.1. The Early Paleolithic ephemeral streams and the intervening alpha Neonile

The cessation of the flow of the Prenile into Egypt seems to have come abruptly; the mighty river did not show any sign of decline in its last stages. It continued vigorously until it was replaced by ephemeral rivers which were fed by local rains. These new rivers, which formed during the Abbassia wet interval, followed the same path of the Prenile. They had their sources in Egypt; the African connection had been severed. They carried a considerable quantity of gravel which they washed from the bare mountains of the Eastern Desert and Nubia, and piled them above the sediments of the Prenile.

The two ephemeral rivers left behind them two thick gravel beds which are named Abbassia I and Abbassia II. These beds are separated by the deposits of a river which formed during an intervening short period of arid conditions, in which the African connection was temporarily resumed. The river which was brought to Egypt by this connection was totally different from the Prenile which also had an African connection. Its deposits were not coarse sands but rather fine-grained silts and structured clays very similar to those of the present-day river, indicating that both must have had the same regimen and sources. It is for this reason that these silts are considered as generations of one river, the Neonile, which ebbed and flowed several times. The earliest Neonile which intervened the Abbassia interval, is named the alpha Neonile to distinguish it from the succeeding Neoniles the beta, gamma and delta Neoniles. The alpha river is also referred to as the Dandara after the small town to the east of Qena (where the famous Ptolemaic temple lies) from which the deposits of this river were first described.

The Dandara was a river of considerable vigour although it must have been much lesser in volume and competency than the Prenile. Compared to the succeeding rivers with an African connection, however, it was mightier. It started first by incising its bed in the sediments of the

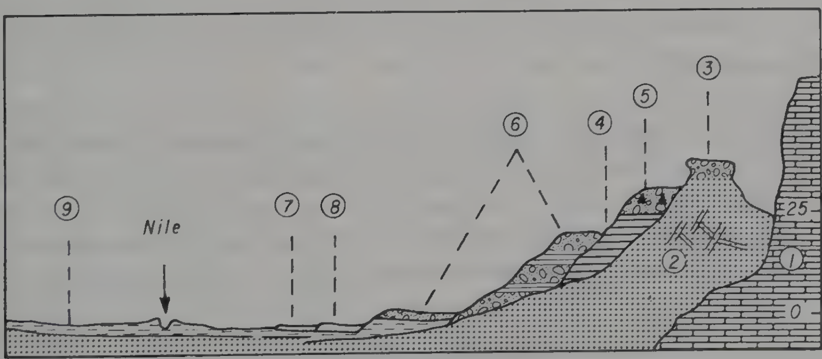

Fig. 1.22. Diagrammatic transverse section across the Nile in upper Egypt, from older to younger: 1. Eocene bedrock, 2. Prenile deposits, 3. Abbassia I gravels, 4. Dandara sils (alpha Neonile), 5. Abbassia II gravels with lower Paleolithic artifacts, 6. Middle Paleolithic gravel and silt terraces, 7. Beta Neonile deposits, 8. Gamma Neonile deposits, 9. modern flood plain.

Prenile and then by aggrading its bed to a height of 23 to 25 meters above the present level of the floodplain. The river, therefore, must have carried a large quantity of water when compared with its successors or with the present-day river. It is likely that the great quantity of water that the Dandara carried was due to a greater influx from the Lake Plateau as well as from the Ethiopian Highlands and the Nubian massif.

The Dandara river did not last long. It was succeeded by the Abbassia II ephemeral river which was similar to the earlier Abbassia I ephemeral stream which preceded the Dandara. Like that older stream, the new river deposited beds of coarse sand and gravel which must have been derived from the same sources and deposited under the same environmental conditions. The gravels of this new locally-fed ephemeral river rest over the deposits of the eroded surface of the Dandara river. They contain abundant crystalline rocks which, like those of the earlier river, were derived from the disintegrated but little leached terrain of the Eastern Desert of Egypt. They are very similar to the gravels which accumulate today along the wadis of the Eastern Desert after the torrential winter rains. The gravels form one of the most distinctive horizons in the entire Nile sequence. They are rich in archeological material of Early Paleolithic (late Acheulian) tradition. The thickness of these gravel beds is about 6 meters although, in places, it may reach 15 meters.

The most famous of these gravel beds are those of Abbassia, near Cairo, from which Bovier-Lapierre (1926), more than 60 years ago, described *in situ* human implements of what was then described as a stratified site about 10 meters thick. These beds were described as carrying "eoliths" in their lower part and Acheulian artifacts in their upper part. Because of the fame of this locality the important gravel beds of these two ephemeral rivers preceding and succeeding the Dandara are named Abbassia I and II respectively, although the site at Abbassia cannot be revisited today for it has been tilled under the foundations of Nasr City, a suburb of Cairo. The most complete section where these gravel beds can still be seen is at the Rus Railway station, half way along the Wasta-Fayum railway line, where the Abbassia gravels are quarried and used for railroad ballast. The ballast pits expose a massive gravel bed made up of well rounded multicolored pebbles, 5 to 10 centimeters in diameter which are derived from the crystalline rocks of the Eastern Desert. The archeological materials separated from the upper part of the bed (Abbassia II) are described as "almost as fresh and as sharp as on the day of their manufacture" (Sandford & Arkell 1929).

While the Abbassia I gravels are found only in the south, the Abbassia II gravels are widely distributed along the borders of the valley and delta forming benches in which they attain a height of about 30 meters above the flood plain in the south and about 15 meters above the modern flood plain in northern Egypt. They make some of the best quarrying sites for gravel in Egypt. The absence of the Abbassia I gravels from the northern parts of the Nile, however, may be taken as an indication that this river was probably not competent enough to fill the entire length of the Nile bed.

The Abbassia II wet pluvial affected Egypt in a grand way, changing its landscape and making a favorable environment for the appearance of man. Frequent rains were common. Lakes dotted the barren deserts and became favorable sites for human habitation. Several sites of Early Paleolithic (Acheulian) have been reported from the Western Desert (Wendorf & Schild 1980), the Nile Valley and along Wadi Qena in the Eastern Desert (Bahay Issawi, personal communication). In the desert they are found at the edges of spring pools, ancient lakes, water-

logged areas or wadis. Along the Nile they are found among the gravels of Abbassian II or in the deposits of wadis discharging into the Nile. All these varied sites were subjected to intensive erosion and are, therefore, of discontinuous nature preventing firm correlation or a complete reconstruction of their history. No faunal or floral remains have been recorded from any of the sites and no absolute dates have been published about them. The evidence, however, is clear that the Early Paleolithic was a wet episode in which the water table of the desert was high, permitting the extensive flow of wells and the formation of large lakes in the midst of the desert, such as at Bir Sahara–Tarfawi area. The rains were also of enough magnitude to support an ephemeral river in the valley of the Nile. The soils which developed at some of the sites during this episode could only have formed in an optimal environment with rains between 250 and 600 millimeters per year.

6.3.2. The early Middle Paleolithic erratic Nile

A long period of an erratic Nile followed the Early Paleolithic. This period, which lasted for more than 200,000 years and during which Middle Paleolithic man appeared, was marked by a river with an African connection which was interrupted many times. The period was marked by a major wet episode, the Saharan Pluvial, which followed the Early Paleolithic (Abbassian) Pluvial after a short period of aridity. During most of its duration, the river received an additional supply of water from the wadis of Egypt which became active during the Saharan Pluvial. The rains of this wet phase came in the winter and did not coincide with the season of the rise of the river; hence they did not raise its level or enhance its floods.

Sediments left behind by this river were recently described from south of Abydos (Paulissen & Vermeersch 1987) where two interfingering layers of Nile silt occur above and below a wadi wash sediment carrying fresh Middle Paleolithic artifacts. This clearly indicates that the wadis of the desert were active, contributing water and sediment during the low season when the Nile flood was not coming. In this respect, this river differed from all other Neoniles which preceded or succeeded it; all of which flowed during periods of aridity and little wadi activity. The explanation of this unusual phenomenon is probably related to the distribution of atmospheric pressure during the glacial period which prevailed during this episode. A detailed discussion of this explanation will be given in section 8 of this part of the book.

The Middle Paleolithic river incised its channel in the sediments of the earlier rivers lowering its level in upper Egypt from the 30 meters level of the preceding lower Paleolithic river to 23 to 25 meters and then to 8 meters and finally to 6 meters above the modern flood plain. These levels mark the periods in which river incision slowed down and terraces formed on the borders of the river. The 23–25, the 8 and the 6-meter terraces include gravels and other materials which were derived from the active local wadis of the deserts of Egypt. The 8-meter terrace contains implements of early Middle Paleolithic (Mousterian) tradition, and it can be followed at a uniform height of about 8 meters above the present day flood plain from Aswan to Assiut north of which it appears to have been removed by denudation. The lowest terrace is traceable at a height of about 6 meters above the modern flood plain between Aswan and Luxor, but further north appears to descend below the present-day floodplain.

This long period of incision was the result of the lowering of sea level brought about by the glacial climate which prevailed most of the time the river was flowing. A glance at Fig. 1.21 shows that the period from about 300,000 to 128,000 years was colder than today. During a good

part of this period man lived along the borders of the river, and his tools were frequently washed and rolled along the slopes of the newly incised valley. The fact that this slope wash is preserved shows that the configuration and slope of the modern valley had already taken shape during this interval of incision and that rains were frequent. It was indeed during that time that the rolling topography of the present-day valley of the Nile was developed. In the southern reaches of the Western Desert that time was marked by the development of great surfaces of erosion and the washing away and redistribution of almost all the sediments of the earlier pluvials. Save for a few relic old surfaces preserved because of very special conditions, the major plains of the south Western Desert are of post Middle Paleolithic age (Said 1983). It is perhaps for this reason that little is known of the middle and Early Paleolithic periods the sites of which had long been destroyed and washed away. We have already noted that some were being washed away and deposited along the slopes of the valley of the Nile as these were forming. The Middle Paleolithic Saharan Pluvial was probably the last of the great pluvials of Egypt. Evidence from the desert shows that it had at least two peaks, during which the Mousterian and Aterian cultural traditions of the Middle Paleolithic flourished.

While the geomorphological evidence points to a rainy climate, the meager fauna, described from the few surviving Middle Paleolithic archeological sites, points to a less rainier time. The fauna includes mixed forms; some required a well-watered environment while others tolerated drier conditions. The former included the warthog; the latter the white rhinoceros, the extinct buffalo, the dama, the red-fronted gazelles, and the camel. The occurrence of these mixed species points to a marginal environment similar to that found today south of the Sahel in the southern range of the red-fronted gazelle, still within the savanna belt but with rainfall in excess of 400 millimeters per year and with extensive stands of acacia (Wendorf & Schild 1980).

6.3.3. The late Middle Paleolithic and Late Paleolithic seasonal beta and gamma Neoniles

During the height of the last (Wurm) glacial the ice sheets covered large areas of Eurasia and north America, and many of the peaks of the mountains of Equatorial and East Africa were covered with snow. The advent of this glacial saw a decline in the precipitation over equatorial Africa and the arrival into Egypt of rivers with an Ethiopian connection. At least two rivers, separated by a period of incision, reached Egypt during the glacial period. These are named the beta and gamma Neoniles. The two rivers tapped their water from the Ethiopian Highlands only; the equatorial sources were receiving considerably lesser rain than today and the Egyptian and Nubian sources had become arid. Having only one source of monsoonal rains, the two rivers were humble and seasonal, probably drying up during the winter. They came laden with sediment, mostly silt, which was piled high along the banks of the river in southern Egypt. The silts are interfingered with layers of dune sand blown from the barren fetches of the Western Desert, and nowhere do they include wadi deposits; the wadis were indeed inactive at the time of the formation of these silts. There were no rains in Egypt; the climate was cold and arid. The desert was abandoned as a habitation site. In this respect, conditions during the last glacial were different from those during the earlier glacials which had been accompanied by wetter climates in Egypt. We shall attempt to reconstruct the meteorological conditions which brought about this situation in section 8 of this part.

There is ample evidence that the headwaters of the Nile, as in earlier glacial times, received lesser rains. The pollen spectra of this age from the Lake Plateau region indicate assemblages dominated by grasses; the African rain forest had shrunk. It did not come back until around 12,500 years before present when grains of forest trees replaced the grasses (Livingstone 1980). Lakes Victoria and Albert, both important sources of the modern Nile, were closed basins before 12,500 years ago. The Sudd region became considerably drier receiving hardly any rain and was reduced to a series of saline lakes (Williams & Adamson 1980). The channel of the White Nile was partially or completely blocked by dunes south of Khartoum until perhaps 12,500 years ago when it was overwhelmed by the flow of the new rains affecting the equatorial lake region. The White Nile did not seem to have contributed any appreciable quantity of water to the flow of the beta and gamma Neoniles whose regimen must have been different from that of the present-day river. The beta and gamma Neoniles derived their waters almost entirely from the Ethiopian Highlands. This must have resulted in rivers that dried up almost completely during winter time although the bed of the river continued to contain numerous pools of water which were often deep and extensive. A parallel case would be the River Atbara today.

Rainfall fluctuations over the Ethiopian Highlands during the last glacial age did not seem to follow the same pattern as that of Equatorial Africa. These fluctuations can be reconstructed from a study of the levels of the lakes of the Ethiopian rift during the last glacial age; the levels would rise when the rains increased and fall when they decreased. Perhaps the best data are from a series of cores taken at Lake Abbe of the Awash basin (Gasse, Rognon & Street 1980). These indicate that there were prolonged intervals of high lake levels between 55,000 and 31,000 years ago (Abbe II) and between 29,000 and 17,000 years (Abbe III). There was then a period of low rainfall from about 17,000 to 10,000 years ago which was followed by a period of greater rainfall (Abbe IV). These data make possible the correlation of the beta and gamma Neoniles with the periods of high rainfall Abbe II and Abbe III respectively. It is interesting to note here that the lack of interdependence between the rainfall pattern in the Ethiopian Highlands and that of Equatorial Africa, evident during the last glacial age, continues largely to this day. We shall show in our discussion of the climate (section 8 of this part) that the present-day rainfall pattern in the Ethiopian Highlands has fluctuated independently from that of Equatoral Africa.

The discharge of the beta and gamma Neoniles must have been considerably lesser than the discharge of the Nile today and their courses must have been braided. Their seasonality does not seem to bar the likelihood that they were never completely parched even during the dry season. The presence of remains of hippo, cattle and hartebeest in the living sites which are associated with the silts of these rivers may be taken as proof that the rivers were never completely dry (Wendorf, Schild & Close 1989). They most likely were diminished to stagnant pools during the dry season.

The sluggish beta and gamma Neoniles carried large quantities of silt which were piled up along their banks in southern Egypt. The absolute ages of the silts of these rivers, which are magnificently exposed in Wadi Kubbaniya to the north of Aswan and in many other locations in Nubia and southern Egypt, were estimated by prehistorians who engaged themselves in the study of the cultural traditions which accompanied the flow of these ancient rivers. Extensive lists of radiocarbon dates are given in Wendorf, Schild & Close (1989) and in Paulissen & Vermeersch (1985, 1987). The absolute ages were determined by the radiocarbon dating of carbonaceous samples associated with the living floors found within these old deposits. The age

of the older gamma Neonile is not known with certainty. It could be between ?70,000 and 25,000 years before present. In Wadi Kubbaniya the lowest and oldest parts of the silts lie beyond the range of radiocarbon dating; they could well be as old as 70,000 years before present. The topmost and youngest parts, on the other hand, "ended well before 30,000 years before present" (Wendorf, Schild & Close 1989). These may not be the youngest of the silts of the beta Neonile which could have been eroded away during the interval of downcutting which succeeded this early siltation phase. In the north at Qena, there occur silts that could well represent the topmost part of the beta Neonile (Shuwikhat silts). They are dated 24,700 years before present (Paulissen & Vermeersch 1989). The Kubbaniya silts include artifacts of the late Middle Paleolithic age while the younger Shuwikhat silts of the Qena area include late Paleolithic artifacts. The two silts may have been separated by a minor episode of downcutting, but this is difficult to prove.

The age of the gamma Neonile is better known. It is dated between 20,000 and 12,000 years B.P. Its sediments carry rich archeological materials of late Paleolithic age. A 5000-year period of incision separated this river from its predecessor, the beta Neonile.

The silts of the beta Neonile lie at a height of 30 meters above the flood plain in Wadi Halfa, gradually diminishing in height northward, reaching only to about 6 meters above the present-day flood plain at Luxor, and practically coinciding in level with the present-day flood plain at Nag Hammadi (Sandford 1934). There are no records of sediments of this age appearing on the surface to the north of the Qena bend. However, in the boreholes drilled in the delta, fluvial sediments with radiocarbon dates that fall within the range of the age of this river are reported at a depth of 20 meters in borehole S7 drilled in the northeastern delta region (Coutelier & Stanley 1987).

The silts of the gamma Neonile have a great areal extension. They occur on both sides of the valley up to the latitude of el-Fashn (145 kilometers upstream from Cairo) and extend for some distance in the mouths of some of the wadis of the desert in Wadi Halfa, Abu Simbel, Aswan and in the plain of Kom Ombo. Northward of el-Fashn the gamma silts are nowhere visible. They assume a height that was never attained except perhaps by the early Dandara (alpha Neonile) river. They are found at heights of 21 and 12 meters above the present-day flood plain at Wadi Halfa and Darau respectively. In the boreholes drilled in the northeast delta, fluvial sediments with radiocarbon dates that fall within the range of the gamma Neonile are recorded at shallow depth.

The source of the massive silts of the beta and gamma Neoniles has been the subject of speculation by different authors. Prior to the discovery of the nature of the climatic conditions prevailing at the headwaters of the Nile, some authors considered these silts to have been derived from an interiorly-drained reservoir, the Lake Sudd, which upon breaching its barrier released a great efflux of waters causing the silts to be swept downstream and dumped below the second cataract (Ball 1939). Other authors advocated the view that these silts were the result of a high and vigorous river (Heinzelin 1968; Said 1981). It is now generally accepted that the silts were formed by flash floods in a semi-arid or arid environment (Fairbridge 1963; Williams & Adamson 1980; Wendorf & Schild 1989; Paulissen & Vermeersch 1989). It is very likely that the flood season was short, but when it came it was strong and in spates. Most of the silt was derived from the mountains of Ethiopia which, during the last glacial maximum, had considerably lower temperatures. The winter temperatures of the high mountains of Ethiopia

during the last glacial were 4 to 8 degrees centigrade lower than today; and there is indication that minor ice caps and valley glaciers were common in areas above 4200 meters in elevation (Messerli & Viniger 1980). The lower temperatures lowered the tree line by at least 1000 meters and reduced the amount of vegetational cover , thus exposing more of the surface to erosion and leading to periglacial phenomena in the high mountains, all of which resulted in a greatly increased sediment load in the rivers.

The piling up of the silts of the beta and gamma Neoniles high up along the banks of the southern reaches of the river during a period of lower sea level (such as the one prevailing during the last glacial when these rivers were active) needs explanation. Rather than incising their beds in response to the lowered sea level, the rivers built up their beds and raised them to unexpected elevations in their southern reaches. This seems to have been due to a series of impediments which obstructed the course of the rivers in the south, at Gebel Silsila (70 kilometers to the north of Aswan) as well as at numerous other places including el-Aqaba el-Kebira, el-Aqaba el-Saghira and Qena (Fig. 1.20). In all these places the river today forms narrow gorges with upstream stretches that have a small slope. In the past they must have formed narrower gorges producing a considerable backwater effect forcing the high water of the rivers to overflow their banks and to inundate the wadi mouths and the plains. The backed up waters of the beta and gamma Neoniles covered the mouth of Wadi Kubbaniya and the great east–west expanse of Kom Ombo (Fig. 1.20), both of which formed ideal sites for habitation by early man. With the exception of the stretch of the valley extending northward as far as Qena during the beta Neonile time and el-Fashn during the gamma Neonile time, the Nile was lowering its bed in the downstream stretches to the north.

6.3.4. The modern river (delta Neonile)

The modern river broke into Egypt following the dramatic events which accompanied the retreat of the ice of the last glacial which had reached its maximum 15,000 years ago. The retreat was complete some 3500 years later. There was a rapid rise of the surface temperature of the oceans between 13,500 and 11,500 years ago. In the headwaters of the Nile this warming trend was reflected by a retreat of the mountain glaciers from their earlier maxima; by 14,750 years before present Mount Ruwenzori was already ice-free.

The retreat of the ice was also accompanied by a period of increased rainfall on the Lake Plateau during the earlier part of this period, between 12,500 and 10,000 years ago, and then on the east African Highlands and the Sahara between 10,000 and 4500 years ago as the wetting front shifted steadily northward. The earlier interval (12,500–10,000 years ago) was a period in which rains increased only in areas which seem to have been "watered by airflows from the Atlantic" controlled by the oceanography of that ocean and the distribution of its currents. These currents were affected by the renewed cooling followed by warming of the waters of the ocean around 11,000 years ago (Street & Grove 1974).

There was a considerable rise in the levels of the lakes of equatorial Africa while there was no significant rise in the levels of the lakes of the East African rift. The level of some of the equatorial lakes rose by more than 100 meters. Lakes Kivu and Tanganyika, which had a level of minus 300 meters during the last glacial, rose around that time to a height of 100 meters above their present level (Degens & Hecky 1974). Lakes Victoria and Albert overflowed their banks and opened up into the Nile some 12,500 years ago, and the Kabarega (Murchison) Falls became

active about that time (Livingstone 1980). Major vegetational changes also took place at the beginning of this poeriod. Pollen analyses of cores raised from boreholes drilled in the equatorial lakes show that the grass pollen which dominated the earlier spectra of the glacial age was replaced by forest tree pollen; the equatorial African forest had come back.

The dramatic increase in the rainfall on the Equatorial Lake Plateau around 12,500 years before present increased the flow of the Nile. The overflowing waters of the equatorial lakes cleared the White Nile from the dunes which had choked its channel during the earlier drier periods, and reached Egypt in large quantities. These waters together with the as yet small supply from the Ethiopian Highlands swelled the river in Egypt causing its level to rise to a height that had seldom been reached before by the Neonile. The first 500-year period which followed the beginning of the great rains of Equatorial Africa was characterized by exceptionally high floods in the Nile (Butzer & Hansen 1968; Paulissen 1985). We shall show in part III of this book the adverse effects of this period of high floods on the settlements of early man who attempted to make use of the Nile environment at that time. With the end of this period, the gamma Neonile came to an end; the Nile had stopped aggrading its bed in Nubia and in the Aswan–Qena stretch. The high floods of this period seem to have eroded away the last of the impediments which used to hold back the water upstream.

The following 2000 years (12,000–10,000 years before present) saw a period in which the river was grading its bed and obliterating the impediments which blocked the course of its southern reaches. In Nubia the process of grading the bed of the Nile was realized by the lowering and deepening of the bed of the river, a process which was already in progress (with minor aggradational episodes) since the time of the beta Neonile and which continued until New Kingdom time. Some of the famous Nubian temples of this Kingdom were built along the banks of the Nubian Nile with a consideration of the level of the Nile which must have been close to that of today. During this period of degradation the bed of the Nubian Nile was lowered by some 30 meters. The rate at which the river was lowering its bed in Nubia, therefore, must have been in the range of one meter per 2000 years. In the Aswan–Qena reach of the Nile the river was also downcutting and deepening its bed. This resulted in the removal of most of the silts of the earlier and older seasonal rivers; the silt which fills the valley today in this reach belongs to the last and extant river. Figure 1.23 is a cross section of the river which shows the configuration of the land in upper Egypt at the time of the arrival of the modern Nile.

North of the Qena bend conditions are not clear. It is possible that the river, which up to this time had been going through a long process of downcutting, started aggrading its bed in response to the rising sea level of this period. In the extreme northern reaches of the delta and judging from the logs of the boreholes drilled there the bed of the river seems to have been aggrading and building up, although many of the boreholes have extremely thin sections for the period between 12,000 and 7500 before present. The large number of boreholes that were drilled in the northeastern reaches of the delta are shown on a map and commented upon in Stanley (1990). Material from several of these boreholes was examined in detail and the results of trace element, heavy mineral and clay mineral analyses are given in several papers published by Stanley and associates of the Mediterranean Basin program of the Smithsonian Institution, Washington, D.C.

With the advent of the Holocene epoch about 10,000 years ago the forcing factors which brought about the early rains of the Equatorial Lake Plateau became operational on the Ethiopian

Highlands and then on the plains of northern Sudan and southern Egypt. There was an increased rainfall over these areas with the northward latitudinal shift of these factors. This rainy interval which affected large parts of Africa is known as the Holocene (Nabtian) Wet Phase. In the East African rift, lake levels rose substantially. Lake Turkana, which was very low after 35,000 years before present, rose at about 9500 years ago to a height that allowed it to overflow and pass into the Nile by way of the River Sobat (Butzer 1971; Nyamweru 1989). In northern Sudan, Nubia and indeed in the entire Sahara, including the desert expanses of Egypt, the increased rainfall changed the landscape of these areas drastically. These totally barren areas, formed during that wet phase a great stretch of grassland or steppe over which nomadic families of hunters roamed following the rainfall; many settled around the numerous playas that studded its landscape. Much of the evidence for this wet phase in these desert areas is archeological such as Neolithic artifacts found in desert areas where man cannot live today, rock drawings of animal species that require at least a savanna type of vegetation, and fossil roots and tree stumps in wadi bottoms where no trees grow today. The Holocene Wet Phase continued with intensity until its decline around 2450 B.C. toward the end of the reign of Dynasty V of Ancient Egypt. A discussion of the effects of this phase in historical time on the Nile levels is given in the section dealing with past climatic fluctuations in Part II of this book. In the deserts of southern Egypt and northern Sudan the phase is reported to have lasted for about 5400 years, during which time it was interrupted by several short periods of lesser rains. Among the large number of papers published about this phase, mention is made of the works of Kuper (1989), Haynes (1987), Petit-Maire (1989), and Pachur (1984).

With the increased rains of the Holocene (Nabtian) Wet Phase the Nile's catchment area became bigger and the river became more vigorous than the earlier seasonal rivers. In contrast to the earlier rivers , the new river received its waters from the Ethiopian Highlands and the Nubian massif as well as from the Equatorial Plateau. The constant supply of its water made it flow freely all year round, albeit with different intensities during the different seasons. The runoffs from the Equatorial Lake Plateau and the Ethiopian Highlands play very different roles in the regimen of the modern Nile . The Equatorial Plateau contributes a small but regular amount to the Nile in Egypt throughout the year; and if this source of supply were to be cut off, as happened with the last two rivers, it can hardly be doubted that the river would run dry in the spring months. The rainfall on the Ethiopian Highlands, on the other hand, is seasonal and comes in the form of a flood. The flood brings to Egypt more than 80 percent of the discharge of the river and also great quantities of suspended matter.

The regimen of the modern river, therefore, owes its origin to the Holocene Wet Phase. Its silt started to build up to the north of Aswan forming the famous agricultural layer of the fertile land of Egypt. In Nubia, however, the river continued, as had been the case with the older rivers, to incise its channel. The oldest of the modern silts, dated 10,600 years before present, occurs at 12 meters above the flood plain in Wadi Halfa (Wendorf & Schild 1974). Following this maximum, the river downcut its bed in Nubia to a level of 9 meters above its modern flood plain during Predynastic times, and then went further down in an interrupted manner to about 5 meters in early Dynastic times, and then to the present level by the time of the New Kingdom some 3000 years ago. There has been very little downcutting in Nubia since that time.

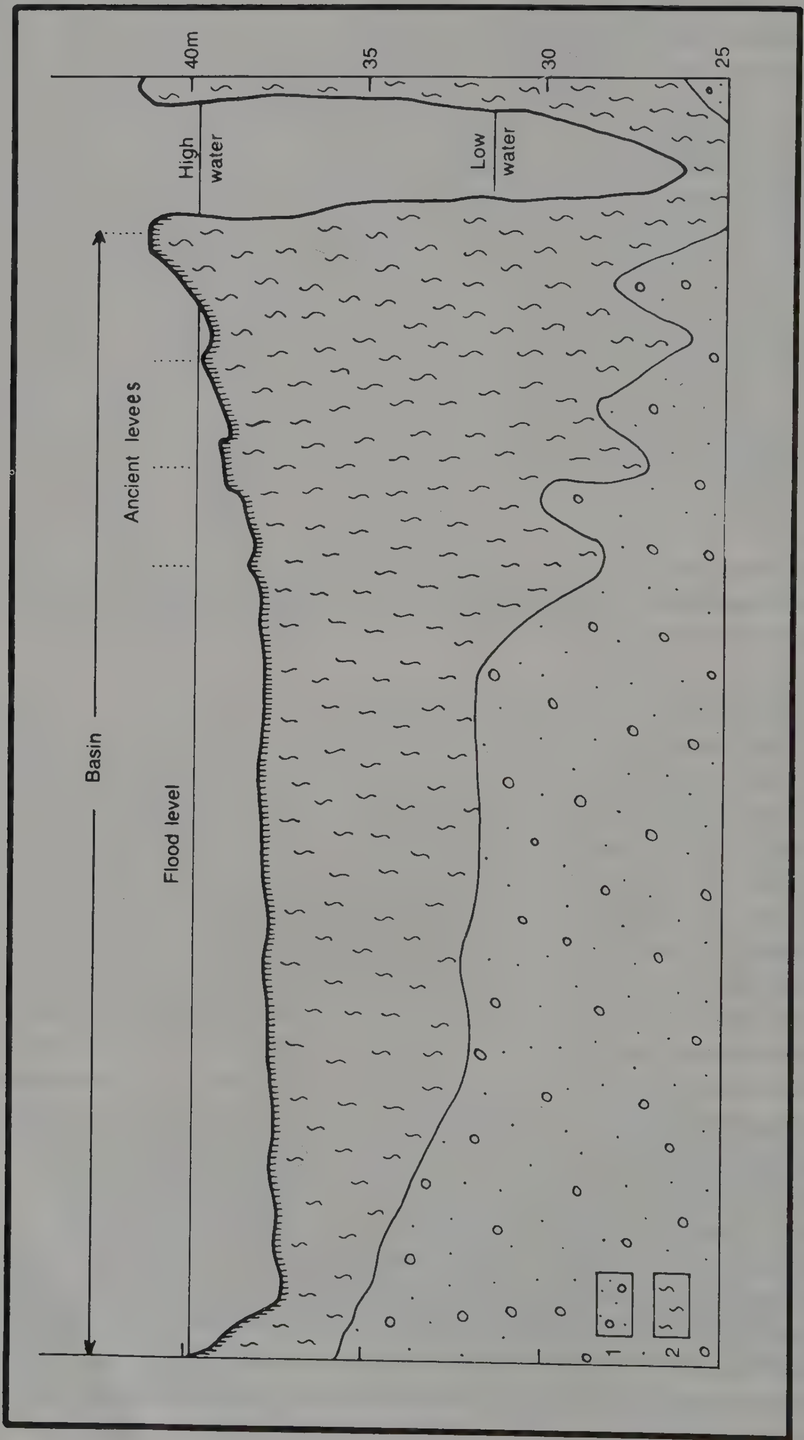

Fig. 1.23. Idealized cross section across the Nile in upper Egypt.

7

THE MODERN LANDSCAPE OF THE FLOODPLAIN OF THE NILE VALLEY, DELTA AND FAYUM

7.1. The Composition of the Modern Alluvium of the Valley and Delta

The alluvial land of the valley and delta consists essentially of the silts of the modern Nile which accumulated in consequence of the river having for the last 8000 years annually overflowed its banks and deposited suspended matter on its flood plains. When freshly deposited the Nile mud is very soft, plastic and sticky. But on losing moisture by exposure to the air it contracts in volume and hardens into coherent earth, and then forms firm ground which constitutes the famed fertile land of Egypt. The composition of this mud is well known and is the subject of enormous literature. The following are a few of the basic references on this subject among many others (El Gabaly & Khadr 1962; Hamdi 1973; Khadr 1961).

The changes of the composition of the deposits of the modern Nile with time have not been worked out in detail. The apparent uniformity of the deposits throughout the entire thickness of the column of the modern Nile deposits with regard to aspect and texture belies the difference in composition which must show in any detailed analysis of the earlier deposits of the Holocene Wet Interval when the wadis of Egypt and the Sudan were contributing additional material. This material must have been tapped from a different provenance than those supplying the river with its deposits today. The latter come mainly from the Ethiopian Highlands (72 percent from the Blue Nile and 12 percent from the Atbara) and very little from the Lake Plateau; the wadis of Egypt and the Sudan contribute little if any to the total sediment load of the river.

Recent studies on the heavy mineral and trace element composition of samples raised from three wells drilled in the northeast delta (Foucault & Stanley 1989; Hamroush & Stanley 1990) confirm that the deposits of the period between 7000 and 4000 years ago differ in compsoition from those of today. Rather than resorting to the simple explanation that this difference is due to the influx of new materials from the active wadis of Egypt and the Sudan during the Holocene Wet Interval, the authors attribute this difference to the decrease in the load from the East African tributaries during this wet period as a result of the increased vegetative cover. In my opinion this conclusion does not take into consideration the changes that affected the Nile Basin and procured for it other sources than those of today.

The mineral composition of the sediments of the older rivers which preceded the modern Nile have been used to determine the provenance from which their sediments have come, by

comparing them with the mineral composition of the sediments of the tributaries of the modern Nile. These come from three main sources which provide the modern Nile in Egypt with its waters and sediments (the Lake Plateau, the Blue Nile and the Atbara). Each one of these sources has its unique mineral assemblage. Four heavy mineral suites (the opaques, the amphiboles, the pyroxenes and the epidotes) form the most characteristic and diagnostic elements of the sediments of the present-day river. The characteristic mineral suite of each of these provenances is given in the following table (after Shukri 1950):

Frequencies of common heavy minerals in the present-day Nile

	Opaques	Amphiboles	Pyroxenes	Epidotes
White Nile	26	15	1	21
Blue Nile	15	56	15	11
Atbara	13	7	75	1
Atbara+Blue Nile	14	31	45	6
Main Nile (north of Atbara)	28	32	30	6

Using these differences many authors attempted to decipher the history of the tapping of the different sources of the Nile by studying the mineral composition of the old Nile deposits and relating them to the different sources of today (Shukri & Azer 1952; Butzer & Hansen 1968; Hassan 1976).

The method is not without flaws, for the mineral suites of the Nile sediments are determined by many micro- and macro-environmental factors which are not fully known or understood. In addition, the Nile, during its history, derived its sediments from sources other than those of today; and it is possible, therefore, that a change in the percentages of the suite of minerals of the old sediments was due to the influx of a new source rather than to the tapping of one of the present-day sources. In practice, the method is of limited use. It can be used in a general and qualitative manner to recognize a sediment which is derived, at least in part, from an African (sub-Saharan) source. For example, the determination of the Prenile as the first Egyptian river to have tapped an African source is based on an analysis of the mineral composition of the sediments of the successive rivers which occupied the valley.

Perhaps the most detailed study carried out on the mineral composition of the old sediments of the Nile is that carried out on a series of stratigraphically and chronologically controlled samples from the beta and gamma Neoniles (the so-called Middle and Late Paleolithic phases of the river) in Wadi Kubbaniya, north of Aswan by Wendorf & Schild (1989). The mineral composition of all the samples is more or less similar irrespective of the age or environment. Overbank silts, soils (which underwent changes after their deposition) and wind-blown sands have the same composition. The samples have a high percentage of amphibole minerals and are similar in composition to the sediments of the modern Blue Nile, pointing to a derivation from that source. The wind-blown sediments seem to have been derived from the incorporated Nilotic sediments.

It is interesting to note here that the amphibole frequency in these samples is smaller than in the series of samples of the same age raised from one of the boreholes drilled in the northeastern part of the delta by Foucault & Stanley (1989). It is possible that the reason for this discrepancy is that the sediments of the north delta were not wholly derived from the Ethiopian Highlands; they probably came, at least in part, from the bed of the Nile as it deepened its channel in the reaches to the north of Qena, as was previously explained. The samples are probably reworked.

7.2. The Thickness of the Modern Alluvium of the Valley and Delta

The thickness of the column of silt left behind by the modern Nile varies in different localities, but it appears from the logs of the numerous boreholes that have been put down in various parts of the valley and delta, mostly for the purpose of obtaining water, that the mean thickness of the Nile mud varies from about 7 meters in the Aswan–Qena reach of the Nile Valley in upper Egypt to about 15–20 meters in the northern part of the delta. The average thickness in the delta is 11 meters, that in the Nile Valley between Aswan and Cairo about 8.5 meters.

The rate at which the Nile mud accumulated in the river and in its flood plain must have varied not only from place to place but also from time to time. Under natural conditions it increased during times of sea rise or times of lower river discharge and decreased during times of sea retreat or times of higher discharge. The only place where the rates of silt accumulation were measured at various times was the well at Roda Nilometer near Cairo (Popper 1951). The rate of accumulation in the river bed changed with time (Fig. 2.27). It was eight centimeters per century between 641 and 1330 A.D., 65 centimeters between 1330 and 1630 A.D., 11.7 centimeters between 1630 and 1841 A.D. and 68 centimeters from 1841 until the end of the nineteenth century. These great changes in the rates may have been due to changes in sea level, the rates increasing with higher sea level and decreasing with lower sea levels. The two periods 1330–1630 and 1630–1840 may have been related to the sea level changes induced by the secondary climatic optimum (1100–1300) and the Little Ice Age of Europe (1530–1850) respectively. During the Little Ice Age of lower sea levels the rates of sediment accumulation in the valley and the delta were considerably smaller than during the period of higher sea levels which followed the period of the secondary optimum.

The estimation of the rate of accumulation of the Nile mud under natural conditions has become almost impossible after the construction of the great irrigation projects of the past two centuries. In the twenties of this century John Ball attempted to calculate the rate of silt accumulation in the areas of upper Egypt which were still cultivated under the system of basin irrigation (Ball 1939). Under this system the river in flood was allowed to overflow its banks and to deposit its load of suspended matter on its flood plain. By carefully measuring that load upon its entry into Egypt at Wadi Halfa and upon its exit past Cairo he was able to know the amount of suspended matter which had settled over the flood plain of the Nile between these two points. Out of 110 million tons of suspended matter passing by Wadi Halfa each year only 58 million tons passed by Cairo. This would make the rate of increase of the thickness of the Nile mud in the basin lands of upper Egypt 1.03 millimeters each year or 10.3 centimeters each century.

For the rate of sedimentation of the Nile silts in the delta no similar studies to those of upper Egypt are available, and probably none will ever be made. The lands of the delta were converted

to perennial irrigation at the beginning of the last century prior to the establishment of a scientific body to record the amounts of suspended matter carried past the canals. Sedimentation rates over the perennially irrigated lands of upper Egypt were less than those over the lands under basin irrigation by about 30 percent. By applying this rate for the perennially irrigated delta, it appears that the amount of sediment which accumulated per unit area on the delta when it was flooded was about 50 percent less than that which accumulated on the basin lands of upper Egypt. These calculations lead one to conclude that the total amount of sediment which was contributed by the modern Nile to the frontal growth of the delta was very little indeed. Out of 110 million tons that passed Aswan annually, fewer than 22 million tons reached the sea, and most of this was moved eastward by the longshore currents. No wonder that the amount of sediment contributed by the modern Nile to the offshore delta sediments is negligible. Stanley (1988) reports low sediment accumulation rates in the middle and outer shelves of Egypt.

The rate at which the mud had accumulated over the land was also calculated by dividing the thickness of the Nile mud which had piled around ancient buildings after the date of their construction by their age. The temples of Idfu and Esna, which were built about 2000 years ago, lie today about four meters below the level of the modern towns, indicating a rate of accumulation of about 20 centimeters per century. In the case of the Karnak temple, the flood plain must have risen about 5.5 meters since its construction in Middle Kingdom time some 4000 years ago. The temple lies today about three meters below the modern flood plain; it was built about 2.5 meters above the flood plain of Middle Kingdom times (see discussion in Part II of this book and Fig. 2.24). The land around the Karnak area, therefore, must have risen at the rate of 14.3 centimeters per century (Ventre Pacha 1896).

Before their removal from their original places, the obelisk of Heliopolis (erected about the middle of the reign of Senwosret (Sesostris) I in 1950 B.C.) and the colossal statue of Ramses II at Memphis (erected in about 1260 B.C.) were found buried under a column of Nile mud the thickness of which was 3.72 and 3.35 meters respectively. This column must have accumulated since the fall of these monuments in ruins. It is inconceivable, as John Ball (1939) assumes, that this column started to form immediately after their erection, for these monuments must have been looked after and cleared from any sediment during their use. I presume, therefore, that the column of mud around these monuments must have started forming since the middle of the first millenium B.C. This would make the rate of silt accumulation close to, if not larger than, that estimated for the Karnak temple.

The historical data indicate that during the earlier part of the Holocene, when the sea level was lower than the present-day level, the sediment accumulation rates must have been exceedingly small, amounting to less than 50 centimeters per 1000 years; most of the suspended matter carried by the river must have gone to the frontal part of the delta which exended then some 20 kilometers into the sea. The 7000 years which preceded the sea rise of the first century A.D., therefore, could not have added to the column of sediment of the modern Nile more than 3.5 meters. The remaining 5 meters or so of this column were built during the last two millenia and, in particular, during the periods of sea rise (first to sixth centuries, 1330–1630 and 1840–1890) when the bed of the Nile and the ground rose at a fast rate. During these periods, totalling about 900 years in duration, close to 65 percent of the rise of the bed of the Nile during the past two millenia occurred. In the early period stretching to the year 600 A.D. the sea stood above the present sea level flooding the northern reaches of the delta and causing

enormous destruction of the land (see section 7.4.2 in this part). During that time the sea is estimated to have risen by one meter. During the period 1330–1630 the rise is estimated to have been about 1.7 meters, while after 1840 it could have been about 30 centimeters. The average rate of accumulation for the entire period must have been in the range of 26 centimeters per century and about 36 centimeters per century for the periods of high sea rise.

7.3. The Floodplain of the Valley

The floodplain of the Nile Valley to the north of Aswan is made up of the fine mud and silt which were deposited by the modern river in the course of repeated seasonal floodings. As the river swelled up every year and started inundating its floodplain it deposited first and immediately along its banks the coarser part of its load. As the flood spread out over the flood plain the velocity of the water and its transporting ability diminished; only finer materials were carried to the plain. This resulted in the faster building up of the river banks, where the coarser material accumulated, than along the floodplain where the finer material was deposited. Consequently, in a cross-section of the river, the high land is always along the river bank forming levees or embankments while the low land is near the desert forming basins which cover the largest part of the plain (Fig. 1.23). This feature is found not only along the main channel of the river but also along its branches. After the flood waters had begun to recede, the levees were left high and dry, while the low-lying basins remained inundated for a long time. Occasionally, the lowest parts continued to harbor perennial waters or marshes. Similarly the groundwater level during the low water season was deeper under the levees than under the basins.

As this process continued, the bed and banks of the river rose at a faster rate than the flood plain, and when the river bed became higher than the plain, the river broke away from its course with the next flood and meandered around, giving the river a braided appearance. In this way the numerous islands, which give the modern Nile its appearance, came into being. The end result was a complicated network of river arms, islands, ox-bow lakes, new or abandoned levees and marshy hollows.

From the time of the onset of the modern river, the greater part of the natural flood plain of the river consisted of seasonally flooded basins and elevated levees. The levees, which were seldom inundated, provided attractive places of settlement from the earliest of times. It is almost certain that many of the villages of present-day Egypt were originally built on these active or abandoned levees and have since then been raised to stand on their cultural debris as it accumulated over the centuries or millenia. The natural levees of the main Nile channel, which today rise between one and three meters above the lowest level of the basin (Fig. 1.24), played an important role in containing the Nile; they were frequently raised and reenforced in the course of history.

Inspite of these efforts, the topography of the floodplain and the course of the river and its distributaries, underwent great changes in historic time. Notable changes occurred in the sinuosity of the river, toward lesser meandering, as the river discharge and sediment load decreased with time (Butzer 1976). There were also shifts in the course of the river and its distributaries amounting to as much as three kilometers. Many of the villages of upper and middle Egypt, which now lie away from the river, were on the banks of the river in earlier times. In Dynastic times the axis of the Nile in middle Egypt seemed to have been west of its present course. Between Akhmim and Cairo the river passed by El-Qusiya, El-Ashmunein, El-Qeis and

Fig. 1.24. The Nile in middle Egypt: 1. sea level contour (in Fayum), 2. stabilized sand dunes (el-Khefoug), 3. Protonile deposits, 4. Prenile deposits, 5. Neonile lacustrine deposits, 6. old bed of Nile, 7. scarp, 8. basalt outcrops.

Memphis, all of which are ancient cities that were built along the banks of the river (Fig. 1.24). In fact, the latter two cities were still on the river in Ptolemy's day. There was a further net eastward shift of the Nile during the last two millenia; the channel in Hellenistic times ran west past Akhmim, El-Maragha, Tahta and Tima (Fig. 1.24). It is likely that the Ibrahimiya Canal, which was redug in the mid years of the nineteenth century, represented an old channel of the river.

Bahr Yussef, the meandering branch of the Nile in middle Egypt, branches since 1870 off the Ibrahimiya Canal at Deirut. In former times it formed an important arm of the Nile which branched off naturally below the valley constriction at Assiut, where a long subsurface limestone ridge divides the valley underneath the modern Nile sediments. Figure 1.25 is a cross section of the river at Assiut showing the disposition of the limestone ridge which must have forced the early river to branch off at this point. The western branch occupied by the predecessor of Bahr Yussef was confined to its channel until it overflowed the ridge and started shifting eastward. The Bahr seems to have had a more westerly course in historical time, passing by Deir el-Muharaq, Meir, Dashlut and Tuna el-Gebel (Fig. 1.24).

In the Memphis area the river bed also shifted in historical time, from the west to the east, leaving behind a series of islands. Figure 1.26 is a map (prepared by the savants of the French Expedition) of the Memphis area in the early years of the nineteenth century, showing the position of the many "*tels*" or hillocks marking the old villages which lay along the older paths of the Nile. These paths were traced by Jeffreys (1985) whose attempt to reconstruct the area in antiquity is given in Fig. 1.27.

The shift of the Nile at Cairo is probably one of the best documented. It affected the life of this vibrant city which continued to expand from the time it was the site of a Roman garrison (Babylon) to the time it became an enormous metropolis at the beginning of this century. Its expansion was at the expense of newly gained ground from a westward-shifting and a better-

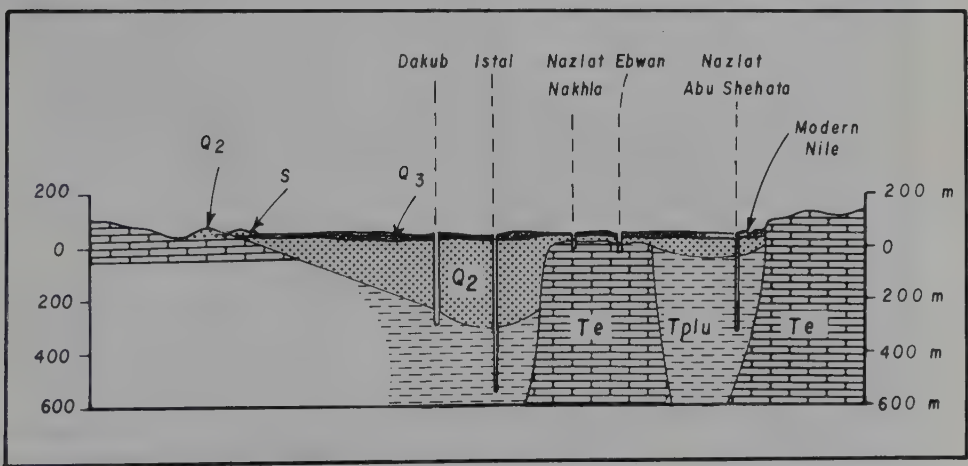

Fig. 1.25. Cross section of the river at Assiut showing the subsurface limestone ridge underlying the Nile deposits: Te. Eocene limestone, Tplu. Paleonile deposits, Q2. Prenile deposits, Q3. Neonile deposits, S. stabilized sand dunes.

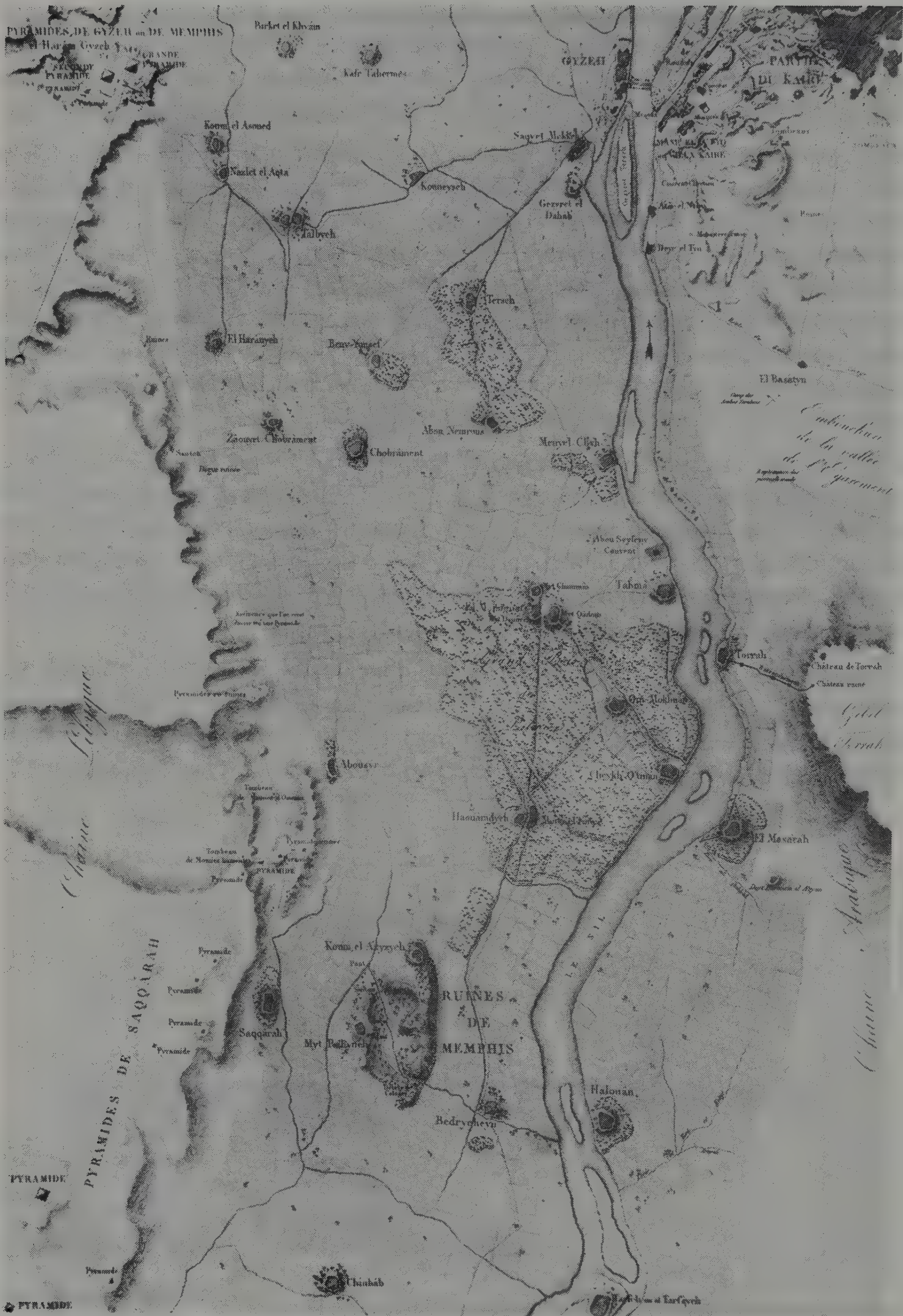

Fig. 1.26. Map of the Memphis area raised by the French Expedition savants, early nineteenth century (from the Déscription de l'Égypte 1812). Note the palm grove areas and the villages which lie on the high tels.

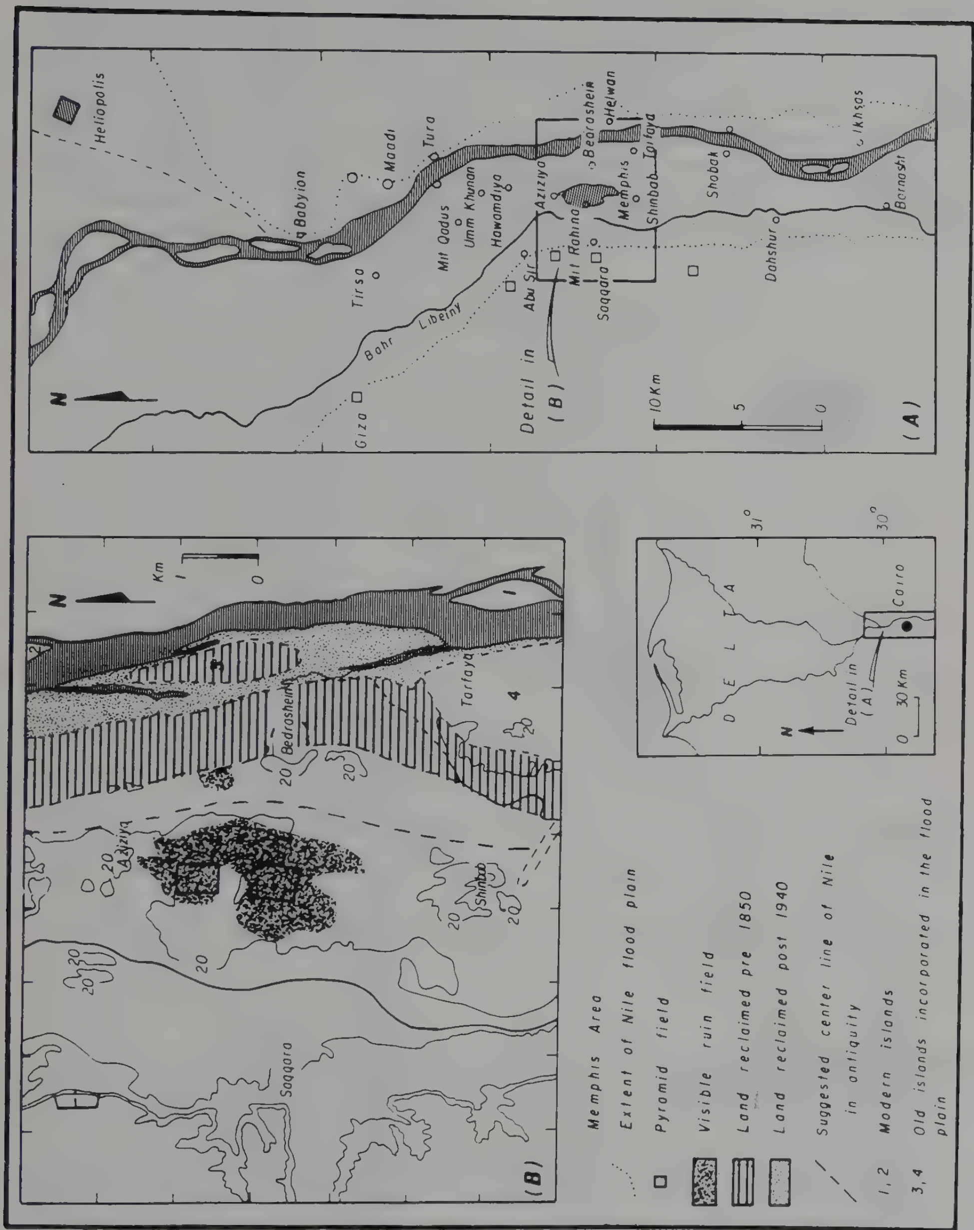

Fig. 1.27. Past river courses in the Memphis area: A. location map, B. detail of Memphis area (after Jeffreys 1985).

controlled river. The history of this expansion forms the subject of a large body of literature. The history of the city of Cairo is documented in the works of Al-Maqrizi (1364–1442), Ali Mubabrak (1880), Lane-Poole (1892) and more recently in Aldridge (1969).

When the Arabs came to Egypt in the mid seventh century A.D. the walled Roman fortress (Babylon) was on the Nile bank and so was the site upon which Amr, the Arab commander who conquered Egypt, built his famous mosque (Fig. 1.28). Today these places are some 525 and 450 meters respectively to the east of the Nile bank. At that time the entire western part of the city was under water. The eastern Nile bank passed along Sidi Hassan el Anwar Street to Sayida Zeinab Square, where the famed Khalig Canal issued, and then along Mohamed Farid Street to Ramses Square (or Midan el-Mahatta where the main railway Station lies today). This latter point marked the place of Cairo's old port, el-Max. Few changes in the course of the Nile

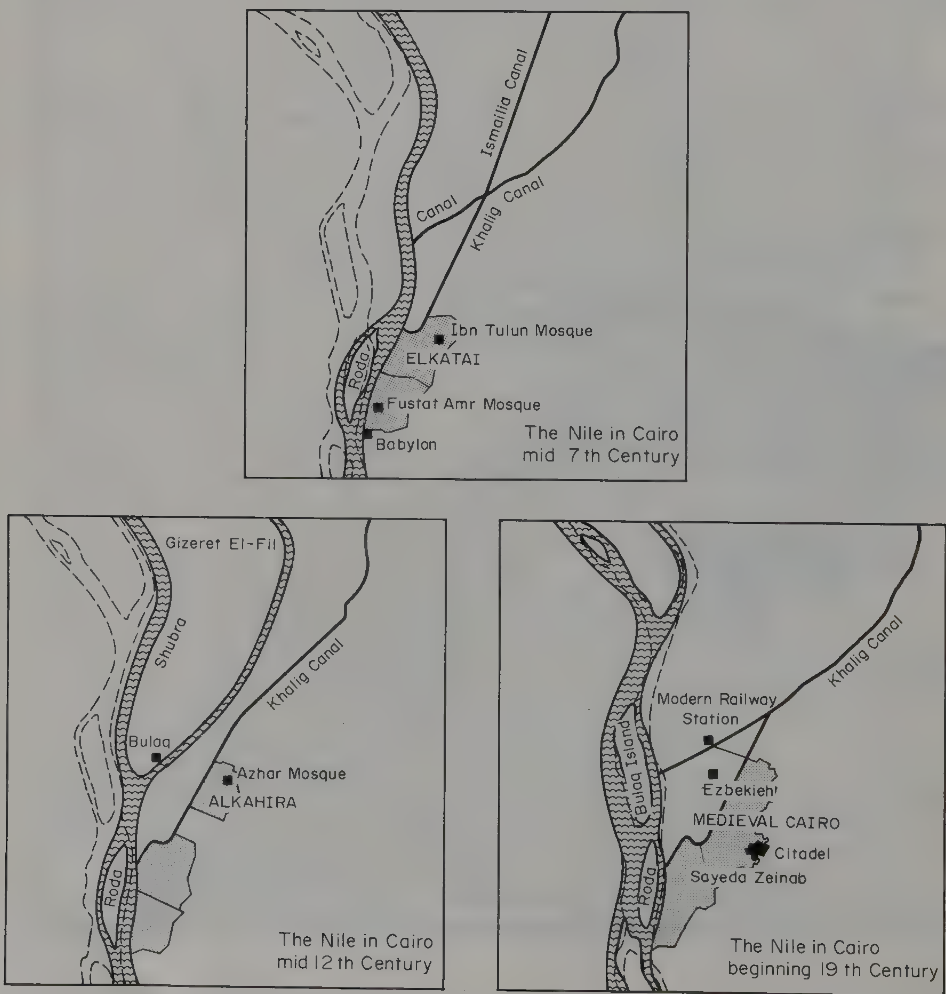

Fig. 1.28a. The river in Cairo: Course of the Nile in the mid seventh century, mid twelfth century and beginning of nineteenth century.

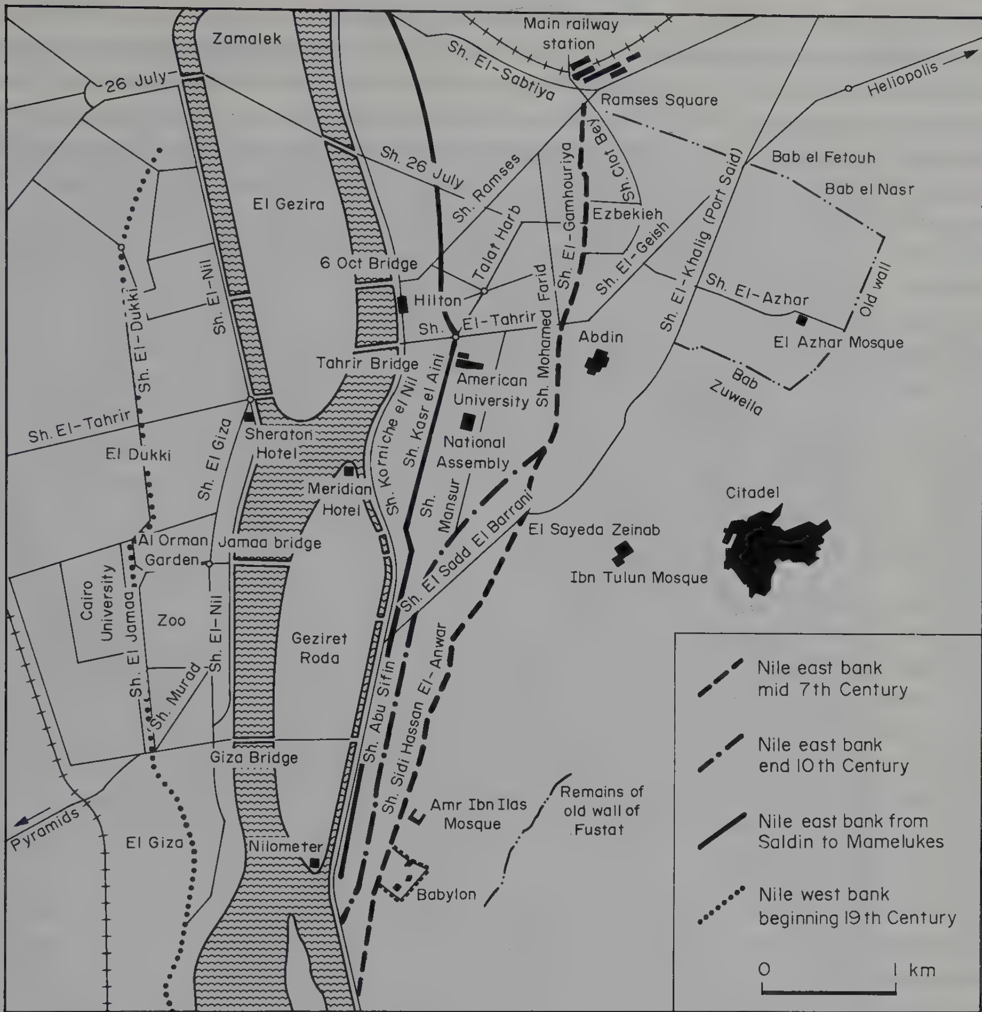

Fig. 1.28b. The river in Cairo: Map showing the position of the shifting banks of the Nile since the Arab conquest.

occurred during the following five centuries. They affected the southern part of the city bringing Babylon and the Amr mosque further away from the river. When Saladin extended the old walls of Fatimid Cairo (Al Kahira) in the latter years of the twelfth century, the river banks were still more or less in the place they had occupied during the previous five centuries. The northern wall was extended westward to the Nile bank to the port of el-Max. On the east, he brought the Fatimid walls south to the Citadel which he built on a site on the Mokattam hills some 80 meters above the city.

During the period of low Niles of the latter part of the twelfth and thirteenth centuries (which will be the subject of a detailed discussion in Part II of this book) dramatic changes took place in the Cairo Nile. The island of Geziret el-Fil appeared in 1174 A.D. as silt started to accumulate

in the vicinity of the old port. At first, the island was small and used to be covered during the yearly inundation, but eventually it grew to enormous dimensions and kept its head above water. It was incorporated into the city when the eastern arm of the river which separated the island from the city silted up in 1280 A.D. Its site is occupied today by Ramses Square, Shubra, Geziret Badran and Sabtiya districts. The southern part of the island formed slightly higher ground that remained above water all the year, and on this ground the town of Bulaq was established as the new port of Cairo in 1313 A.D. The new port replaced the el-Max old port which became inaccessible as the river bed shifted. Bulaq, which is now part of the city, was then a couple of kilometers away from Cairo, which was never quite on the river; when the French Expedition arrived in Egypt a road ran from the port up to Ezbekiya through open fields. The second island which appeared in the Nile at about 1300 A.D. was the island of Bulaq which forms today the Gezira and Zamalek districts. The westward shift of the river continued up to the nineteenth century, leaving large tracts of low swampy land with many pools and lakes which were still there when Napoleon came. They appear on the map of Cairo which was raised by the French Expedition (Fig. 1.29). Among the most prominent of these were the Ezbekiyah and Birket el-Fil lakes. On the water front of the Ezbekiyah lake lay the most fashionable homes of Cairo. The site of Birket el Fil is occupied today by the Hilmiya quarter.

The land which emerged around Geziret el-Fil was marshy and soft. It was drained in the middle of the fourteenth century when al Nasir extended the Khalig canal from where it issued at Sayeda Zeinab Square to the new bank of the river through this new swampy land. The Khalig canal, which was the site of the yearly ceremony of the "cutting of the dam" preceding the sowing season in Egypt (described in section 2, Part II), was filled in the latter years of the nineteenth century. Its place is occupied today by the Khalig Street (renamed Port Said in 1957). During that time Cairo had another canal which emanated from where the Nile Hilton Hotel lies today and joined the Khalig Canal at Ghamra, a few kilometers to the east. Its place is now occupied by Ramses Street.

Efforts were made during the latter years of the nineteenth century to stop the westward shift of the Nile and to stabilize the levees of the river. Massive blocks were used to obstruct the western arm of the river which runs at the foot of the Roda and the Gezira islands, in order to force the waters to flow into the eastern arm. In the meantime, the western embankment of the river along the Giza Street was reenforced. These efforts stabilized the river in Cairo and stopped its westward shift. This stabilization made possible the growth of the city across the river in the Giza Province when the western flood plain was drained and filled up; it now forms the Dokki, Agouza and Giza districts.

7.4. The Delta

The present-day Nile delta is made up of a massive unit of sand and gravel which is overlain by a thin layer of alluvial clay. The top alluvial layer of the modern delta was built up during the past 7 to 8 millenia as the water and sediment of the modern Nile spread out over the delta expanse and the river bifurcated into branches or arms. The levees were usually low and the basins so deep that some were converted into perennial swamps or, as in the case of the northern reaches, brackish lagoons. The latter evolved into lakes when they were cut off from the sea by the silt and sand bars formed by the eastward longshore currents of the sea. Inspite of the ubiquitous presence of perennial swamps the delta offered a favorable site for the settlement of

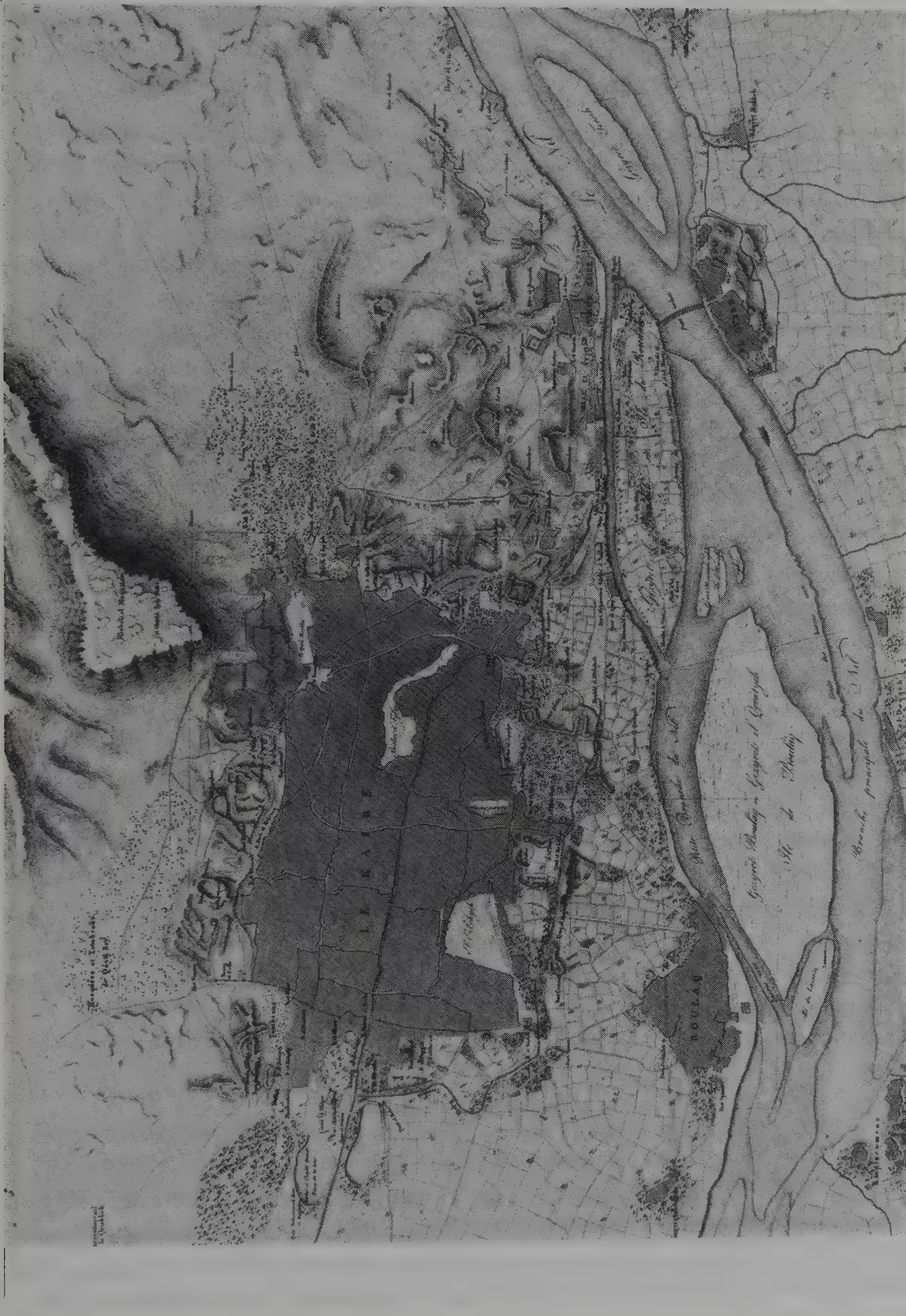

Fig. 1.29. Map of Cairo raised by the French Expedition savants, early nineteenth century (from the Déscription de l'Egypte). Note that the western branch of the Nile was the main branch of the Nile and that Bulaq was separated from Cairo.

early man even during times of an advancing sea, for it was favored by having, in addition to the levees, numerous sand mounds and flats which stood above the level of the ground and had a commanding view of the landscape. The mounds, the so-called "gezireh" or turtle backs, could be the remains of the early Prenile sand deposits which escaped erosion when the river and its arms deepened and incised their channels through them. The flats are extensive sheets of sand representing stabilized ancient dune fields which probably formed, as at present, along the stretches of the coast. Figure 1.30 shows the distribution of these mounds and flats.

The bifurcating channels of the delta were more numerous during most of the Holocene, fanning out as far eastward as the Pelusiac branch and as far westward as the Canopic branch. Figure 1.30 shows the branches of the delta and the most important cities of historic time. It is based on information obtained from Tousson (1922); Wilson (1955); Kees (1961) and Butzer (1976). Seven major branches of the delta are mentioned in various historical documents and in ancient maps. Five of them degenerated and silted up in the course of history; two, the present-day Damietta and Rosetta branches, remain active. The channels evolved during periods of low sea level and probably took their final shape during the period immediately following the rapid sea level rise, which occurred at about 5000 B.C. By Predynastic time most of the branches were developed and their banks offered favorable sites for settlement (Brink 1987). During the Ramesside period there were five branches (Fig. 1.31). These were named the western river (Canopic), the water of the God Ptah (Bolbitine), the large river (Sebennytic), the water of the God Amon (Phatemic) and the water of the God Ra (?Pelusiac) (Bietak 1975).

The silting up of some of these branches seems to have occurred during periods of lower Nile discharge, which usually instigated dire times, weak governments and neglect in clearing the beds of the distributaries. As will be shown in Part II of this book, the Pelusiac branch started silting up during the period of low Niles in the second millenium B.C., when it was separated from the sea by a series of accretionary coastal sand ridges (Sneh, Weissbrod & Perath 1975). In the west the Canopic branch silted up as a result of the re-excavation of the Bolbitic branch which took place about 300 B.C. (Sestini 1989). Because a re-excavated canal has less meanders and greater gradient than a natural branch it was capable of usurping a large part of the water passing through the bifurcation of the delta branches to the north of Cairo. The Rosetta branch receives today more than 70 percent of the water of the Nile as it bifurcates into the delta fan. Indeed, had it not been for the continuous effort of the irrigation engineers the Damietta would have silted up long ago. The other branches of the Nile started silting up early on, but they finally disappeared during the eleventh, thirteenth and seventeenth centuries when the Nile had exceptionally low discharges.

7.4.1. Evolution

The Nile delta has a complex geological history which makes it truly unique among other deltas of the world. The delta which we see today is but the last of the deltas which formed at the mouth of the river as it evolved. Underneath the modern delta lie other deltas of different aspect and origin that were formed by the river as it changed its sources, the amount of water it carried and the type of sediment it deposited. Each of these deltas reflects the regimen of the river which affected its formation. Figure 1.32 attempts to reconstruct three of the deltas which developed at the mouth of the river and which lie one on top of the other. The earliest of these deltas was that of the Eonile which was formed as an apron in the North Delta Embayment which

Fig. 1.30. The Nile delta in historic time showing the ancient branches, nomes and historic cities (historic names are in brackets underneath the modern names). The dark offshore contour line marks the shore line of the delta during the height of the last glacial.

Fig. 1.31. The delta during the Ramesside period (after Bietak 1975).

lay in the shadow of the high South Delta Block. Its sediments are coarse. They were derived from the elevated Tertiary rocks of the Eastern Desert of Egypt.

The succeeding Gulf phase, which followed the formation of the Eonile delta, filled the North Delta Embayment with marine sediments and levelled it with the eroded South Delta Block, so that when the Paleonile arrived some two million years later its delta started fanning out immediately to the north of the Cairo high. The waters of the Paleonile carried fine-grained sediments which were less dense than the marine waters of the sea into which they were flowing. They flowed over the surface of the salt water, advancing into the sea as they met little resistance in front, and deposited their load along the sides. Along these overstretched protrusions of each tributary into the sea a delta of the bird's foot type seemed to have formed. The sediments of a bird's foot type of delta have the best potential for the development of stratigraphic traps. Most, if not all, the oil and gas fields of the delta lie within these sediments.

A long time elapsed before the Prenile arrived in middle Pleistocene time carrying an enormous load of coarse sands and gravels. The waters of this river must have been denser than the marine waters into which they were flowing. This caused the deposition of the load as it met the sea in a broad and expanding front forming an arcuate delta. When it was fully formed some 400,000 years ago, the delta of the vigorous Prenile assumed enormous dimensions, extending well into the Mediterranean Sea and having an area at least four times that of the modern delta. After the cessation of the flow of the Prenile the Nile became a marginal river with tenuous connections with the sources from which it derived its waters. This marginal river, called the Neonile, had short-lived and widely-interrupted episodes of aggradation which were separated and offset by long episodes of degradation resulting in a net degradation of the Prenile delta. The relic of that delta forms the core of the delta of the modern river and is responsible for giving it its present-day arcuate shape. We have already mentioned that the Neonile added little sediment to the mass of this relic or to its frontal advance. An average of barely 35 million tons of sediment were spread annually over the delta expanse by the last of the Neoniles for the past 7 to 8 millenia. These sediments, which make up the top alluvial soil of the delta, form a thin crust which overlies a massive unit of sand and gravel deposited by the middle Pleistocene Prenile. The modern delta, therefore, is passing through a phase in which the processes of destruction are at a halt.

Figure 1.33 is a diagrammatic longitudinal section across the delta based on available drillhole data obtained from Attia (1954), Wunderlich (1987) and Coutelier & Stanley (1987). It shows the evolutionary stages of the delta since it acquired its maximum size at the end of Prenile time. Three surfaces marking critical stages in the development of the delta are shown in the figure. The first is conjectural; it marks the assumed surface of the mammoth delta of the Prenile. The second is the surface of erosion which existed when the beta seasonal Neonile reached Egypt some 70,000 years ago. It marked the end of a long period of erosion which lowered the surface of the Prenile delta to its present-day level and moved back its front almost to its present-day position; the core of the delta as we know it today had been formed. The third is the surface of erosion which existed when the Neonile ended its early stage of incision some 8000 years ago. The southern stretch represents a net degradational surface while its northern stretch is aggradational, resulting from the accumulation of the reworked sediments which were primarily picked up from the degrading upstream bed of the Nile in Egypt. The present-day ground level is a surface of aggradation that was formed during the past 7 to 8 millenia.

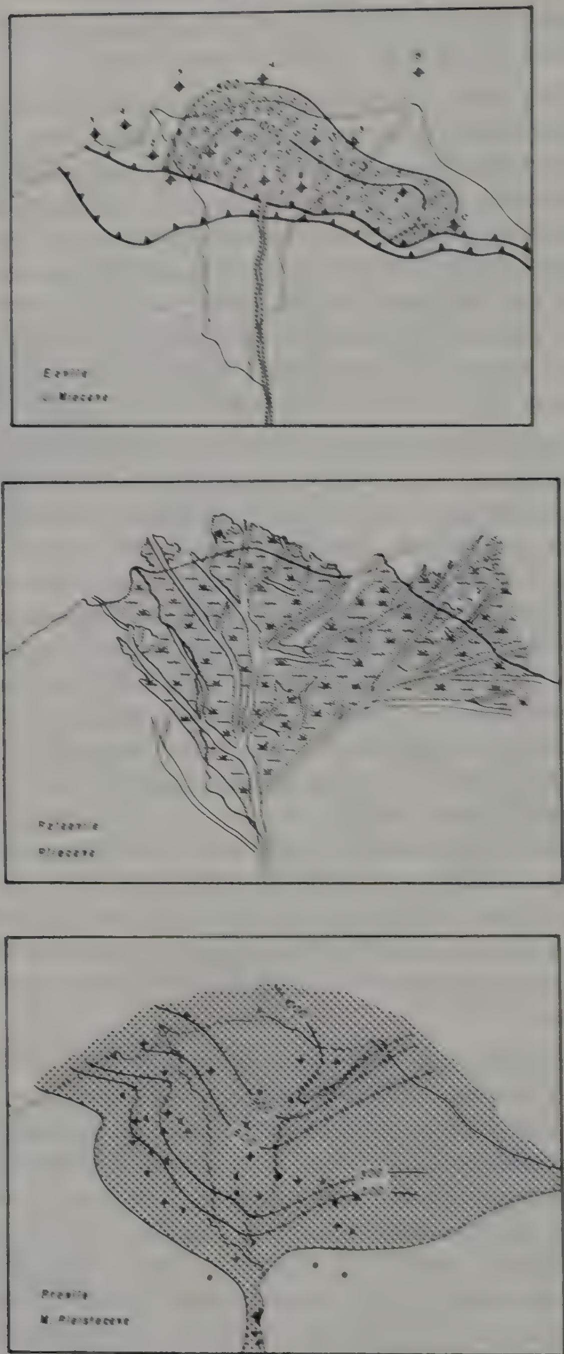

Fig. 1.32. The succeeding deltas of the Nile in (from top to bottom) late Miocene, late Pliocene and middle Pleistocene time.

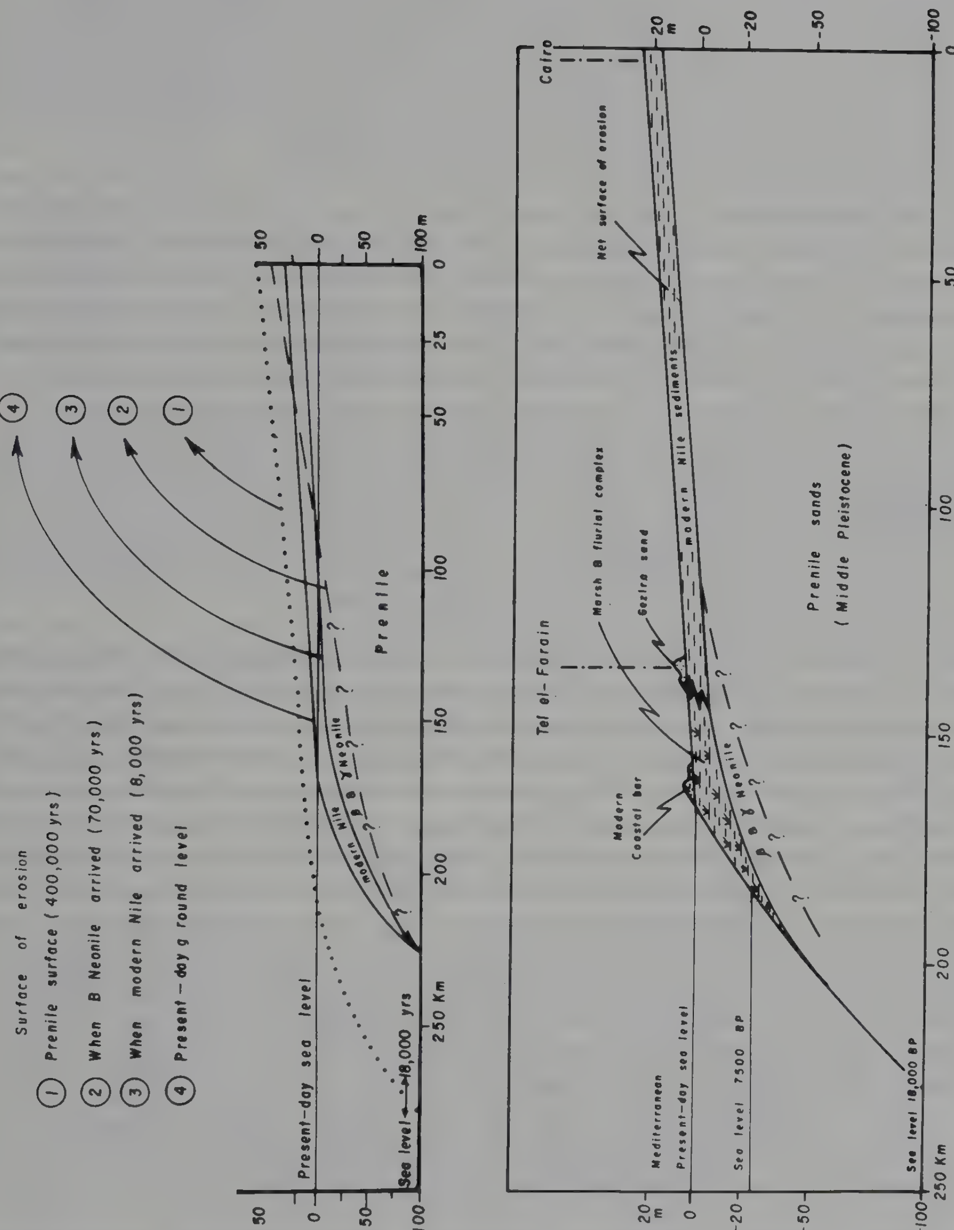

Fig. 1.33. Diagrammatic longitudinal section across the delta from Cairo to the Sea.

7.4.2. Effect of sea level fluctuations

The northern part of the delta has been and is still under the influence of the sea which has changed its level since the time of the last glacial when it stood about 100 meters below the modern sea level. At that time, and for a long time thereafter, the delta must have extended well into the offshore area of the sea constituting a potential living site for Terminal Paleolithic and Neolithic man. Figure 1.30 shows the shoreline of the delta during early Holocene time before the great sea level rise which occurred after the retreat of the last glacial. The uncovered continental shelf is steeper than the subaerial plain of the delta, sloping about 88 centimeters per kilometer versus 27 centimeters per kilometer for the delta proper.

The start of the retreat of the ice of the last glacial age some 15,000 years ago was accompanied by a warming trend which continued steadily except for a short time between 10,500 and 9500 years ago when it was reversed (COHMAP 1988; Lighty, Macintyre & Stuckenrath 1982). About 5000 B.C. the warming trend reached its maximum and the average temperature was at least 2 degrees celsius higher than today. About that time the sea, which stood 4 to 5 meters below the present level, inundated the northern peripheral parts of the modern delta. This inundation did not affect the eastern part of the delta which remained above the sea. This was due to the fact that this part received the bulk of sediment of the Nile branches most of which flowed in that direction as has happened since the late Miocene (Harms & Wray 1990). The rate of sediment accumulation in that part seems to have exceeded that of the sea rise. There was another sea level rise around the year 2000 B.C. when the sea level stood at about one meter below the present level and the coastline along the Rosetta branch was about 7 to 8 kilometers inland from its present position (Chen, Warne & Stanley 1992).

The rise of the sea continued until, by the first century A.D., the sea encroached on the eastern stretches of the delta for the first time. Excavations along the defunct Pelusiac branch of the delta, which debouched to the east of the mouth of the present-day Suez Canal, show that the shoreline stood about 10 kilometers inland in the year 25 A.D. (Sneh & Weissbrod 1973). The coast off Rosetta also stood inland during that time. In the first century A.D. the Roman port city of Balbouthys was located on the sea front. Today its ruins are 14 kilometers inland from Rosetta (Sestini 1989). The continuous rise of the sea level during the following centuries affected mainly the northeastern part of the delta which became fully inundated in the early years of the seventh century A.D. It is possible that the silting up of most of the eastern branches of the delta and the reduction of the amount of silt that used to partially offset the effect of the rise of the sea level speeded this process. The inundation of these lands resulted in the loss of the rich agricultural lands of the northeatstern belt of the delta and their conversion into an alkaline wilderness highly charged with salts (Hume 1925; Russell 1966). Lake Manzala probably originated and assumed its present form during this period when it was first alluded to in the contemporary Arab chronicles which speak of the cities and ports of this belt conducting a lush trade with the Levant, Venice and other Mediterranean city states. They vanished prior to the Arab conquest of Egypt in the mid-years of the seventh century A.D.

Among the more recent fluctuations of the sea level mention is made of the sea advance during the fourteenth and seventeenth centuries following the Climatic Optimum and its retreat following the Little Ice Age. During the latter age, which extended from the seventeenth to the middle of the nineteenth century, the sea seems to have retreated and the delta expanded

offshore. Many Turkish sea-front forts of that period were built on sites which are now under water. The retreat of the coast to its present-day outline must have started since at least the latter part of the nineteenth century (Said 1958).

The northern reaches of the delta which were flooded during the periods of inundation are shown in Fig. 1.30. They include the belt of lagoons and low lands which lie in the shadow of the barrier coastal sand dune complex. As habitation sites they seem to have been of marginal nature during most historic time. In fact, these reaches remained in their natural or barely modified condition until the mid years of the twentieth century. With the exception of a few fishing villages they remain sparsely populated until today. There are no records of old settlements from this belt. Recently Stanley, Arnold & Warne (1992) reported the presence of a few ceramic shreds from a borehole at the southern tip of Lake Burullus which is supposed to have been drilled in a "protected margin of lagoon environment" which was "seasonally flooded by the Sebennytic branch of the Nile". The oldest of these shreds (? New Kingdom times) were raised from a depth of 9.4 meters. The site does not represent a living floor. The shreds could have been dumped into it and the depth at which they were found in the borehole does not necessarily represent the level of the ground at the time they were used.

Save for these northern reaches the delta up to its very northern parts has been densely settled since Predynastic time. The Amsterdam University Archeological survey conducted in the 1984–1985 season (Brink 1987), reported 92 mounds or tells (arising from settlement debris) from various periods within a 30x30 kilometer area around Faqus alone. Buto, Tell Tennis and Diospolis inferior, which lie at the extreme northern peripheries of the delta, were already important towns in early dynastic if not Predynastic time. Tell Tennis seems to have lain on a sand bar in Lake Manzala that probably marked the shore line of the time. Its mere existence above sea level to this day belies the contention that the delta is undergoing subsidence. Recent archeological work in Tell el-Farain (Buto) shows that the living floors of Predynastic time lay some 3 to 4 meters below the present sea level (Wunderlich 1987, 1989). This means that the site had accumulated that much thickness of silt since Predynastic time. In the northeastern part of the delta, however, Predynastic sites are reported at the same level as the present-day sea at Minshat Abu Omar (Kroeper 1987). This may be taken as an indication that the rate of sediment accumulation in this region decreased considerably after Predynastic time. Both sites give further evidence that there has been little if any subsidence since Predynastic time.

In spite of the small rates of subsidence that these sites indicate, Stanley (1988, 1990) reports considerably larger subsidence rates in the northeastern part of the delta and especially in the Lake Manzala area. The numerous boreholes drilled in this area give anomalous thicknesses for the modern Nile deposits. In contrast to the relatively small thicknesses of the Holocene column in the northern reaches of the delta, the column below Lake Manzala reaches, in places, 50 meters. This prompts Stanley to advance the view that these sediments must have accumulated in a subsiding tectonic basin. The radiocarbon-dated base of the modern Nile section shows that this column of sediments started building up about 7500 years ago when the sea level stood, according to Milliman & Emery (1968), at an elevation of 24 meters below the present sea level. Since this column of sediment lies today at a depth of 50 meters, that is 26 meters below the sea level at which it was formed, the column must have subsided by at least that much. According to Stanley, this was due to deposition in a basin with a continuously subsiding bottom. A subsidence of 26 meters in 7500 years means that the column was subsiding

at a rate of about 3 to 4 millimeters per year. This alarming rate of subsidence prompts Stanley to warn of the dire consequences that could befall the overpopulated northeastern part of Egypt if this rate were to continue for several decades.

This extremely high rate of subsidence stands out when compared with the small rates of subsidence reported from the immediate surroundings of the lake. The contrast becomes even greater when one considers the subsidence to have started at the time of the first appearance of Lake Manzala (i.e. seventh century A.D.), and not from early Holocene time. If the data upon which these rates are based proves correct, then Lake Manzala must represent a subsiding hole along the northern rim of the delta resulting from some unusual tectonic process. However, there is also the possibility that the data are flawed. In the first place, many of the radiocarbon dates given are obtained from carbon extracted from shells and should, therefore, be regarded as minimum ages rather than absolute ages. In the second place, there is no concensus with regard to the level of the sea some 7500 years ago. In fact, Stanley himself changed that level from 24 meters below the present-day sea level in his 1988 paper to 13 meters in his 1990 paper. In addition, if we are to extend the logic used by Stanley in calculating the rate of subsidence of Lake Manzala to other areas of the delta where the thickness of the Holocene section is small and where the lower beds lie above the assumed level of the sea at the time of their formation, we would come to the most unlikely conclusion that these beds must have been elevated since the time of their formation.

The composition of the Nile delta gives further credence to the view that the delta does not seem to have been subjected to subsidence. In our discussion of the evolution of the delta we have already shown that it is made up of a core of sand and gravel with a thin veneer of silt and clay. This composition puts the Nile delta in a class by itself. Most if not all other deltas have a sedimentary column which is made up mainly of clay and is, therefore, subject to compaction and subsidence, which is compensated for by the annual supply of sediments spread over its surface. In contrast, the Nile delta is not subject to compaction and does not seem to depend on sediment supply to sustain itself.

7.5. The Fayum

The Fayum is a circular depression in the limestone plateau of the Western Desert (Figs 1.24, 1.34) which lies below sea level and is bounded by cliffs from all sides. The ridge to the east, which separates the depression from the Nile, is breached by the Hawara channel through which the river waters at flood time obtained access to the depression converting it into a lake of considerable dimensions in certain intervals of the Holocene and probably also in earlier times. The Fayum is unique among the provinces of Egypt; for although its lands are watered today by the direct flow from the Nile its drainage does not pass back into the river or the Mediterranean but into a brackish lake, situated some 45 meters below sea level in the lowest part of the province, where it is disposed of by evaporation from the lake surface. It thus has affinities, on the one hand, with the oases and the great depressions of the Western Desert which are devoid of drainage outlet and, on the other hand, with the provinces of the Nile Valley and Delta which are watered by the river.

The Fayum is unique also in that it exposes some of the older sediments of the modern river which, as we have seen, is concealed beneath the surface in the Nile Valley to the north of Aswan. The district is also of considerable historical interest as it involves the much disputed problem

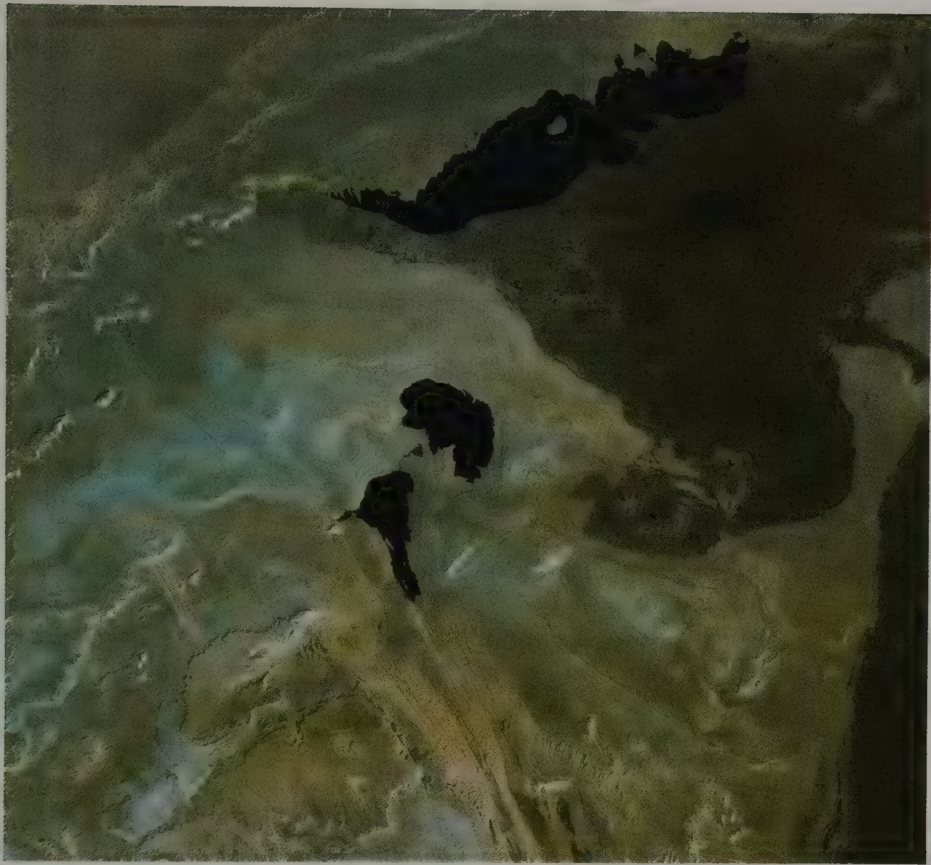

Fig. 1.34. Satellite image of the Fayum.

of the extent of Lake Moeris of antiquity which was visited by Herodotus in about 450 B.C. and was described by him as an artificial lake, 3600 furlongs in circumference and 50 fathoms in depth, in which the water flowed from the Nile six months of the year and flowed out of it to the Nile during the remaining six months. It is certain that the lake of our own day, the Birket Qarun, is the shrunken remnant of this ancient lake. The mass of evidence that has accumulated on the Fayum indicates beyond any doubt that the district is a natural excavation and that it was occupied by a considerably larger lake during the time of the visit of Herodotus. Doubts about the existence of an extensive lake at the time of Herodotus were raised by Caton-Thompson & Gardner (1934) who concluded, from their study of the ancient beaches of the former lakes which occupied the depression and their prehistoric artifacts, that the lake was extensive and high during late Paleolithic time when people settled around its beaches and that it shrank in late Neolithic time and has remained low since then. These authors conclude, therefore, that the historic Lake Moeris could never have been large nor could it have discharged into the Nile in the manner described by Herodotus. Later work by The Combined Prehistoric Expedition reversed the order of events described by Caton-Thompson and Gardner and showed that the lower sites were not of Neolithic age, as advocated by Caton-Thompson and Gardner, but were,

in fact, considerably older than those described from the higher terraces of the depression and that the people who lived at the lower levels of the lake followed the lake as it rose, the lake remaining high since that time and during most of historic time (Said et al 1972; Wendorf & Schild 1976).

The origin of the depression is controversial. Most authors believe that it was formed long after the Nile had established its course and that it probably took shape as recently as 2 or even 1 million years ago. It could not have been in existence during the Pliocene for it was not overwhelmed by the marine gulf of that time. It was probably formed by the dissolution of the limestone beds into which it was excavated during the intensively wet periods of the past. This resulted first in the formation of subsurface caverns which developed as the surface water rich in carbonic acid seeped through the surface cracks and dissolved the limestone beds. This was followed by the caving in of the roofs and then by the blowing away of the resultant fine material by wind during the arid periods which followed and intervened with the rainy periods. Underground caves are known to exist in many areas in the limestone country of Egypt, but none is of the dimension and the neat circular shape of the Fayum depression. The limestones of the Fayum area are unique in their nature. They differ from all other calcareous rocks of other areas of the same age in being more friable and in including larger quantities of impurities.

The depression does not preserve a great thickness of washed material or Nile sediments above its bedrock. A borehole in the depression hit bedrock after penetrating 8 meters of mostly Nile silts and lacustrine deposits. The absence of washed-in materials from the walls of the depression during the pluvial periods of the Pleistocene can be attributed to the fact that these materials were so fine that they were blown away as they were formed or soon thereafter.

The channel which connects the depression to the Nile must have developed first as a gully which, under the erosive action of rain, cut its head backward until it breached the divide which separated the depression from the Nile Valley allowing the flood water s , when they reached the height of the channel, to sweep down into the depression. The depth and configuration of the channel are known from a series of boreholes which were sunk by the Geological Survey of Egypt (Fig. 1.35). The channel is cut in the Nile–Fayum limestone divide to a depth of minus 17 meters below sea level or about 28 meters above the lowest point of the depression.

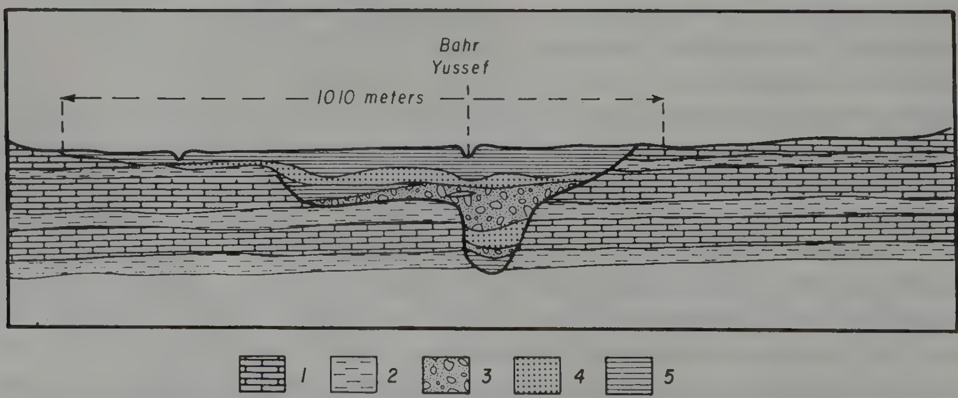

Fig. 1.35. Section across the Hawara channel from borings made by the Geological Survey of Egypt in 1934: 1. limestone, 2. marls, 3. gravel, 4. sand, 5. Nile mud (after Ball 1939).

The earliest connection of the depression with the Nile seems to have been affected by the tumultuous Prenile whose high water filled the depression to an elevation of 43 meters above sea level (or 88 meters above the bottom of the depression). The 43-meter sand and gravel terrace described by Little (1936) on the northeast side of the depression is devoid of any archeological material, and although it cannot be definitively dated it can be correlated with the Prenile deposits. The retreat of the Prenile left the Hawara channel filled with sand and gravel beds some of which are still to be found between depths of minus 17 and plus 10 meters (Fig. 1.35). The connection with the Nile was then severed for a long time. The low and erratic Niles of the middle and late Paleolithic did not seem to have reached the height necessary to overflow the silted-up Hawara channel into the depression. This became possible by the modern Neonile, a connection that started around 9000 B.C. and has since then been severed and re-established repeatedly. The connection converted the depression into a lake and served as an escape for the flood waters of the Nile.

The beaches that the lake left behind at different levels were favored sites for settlement by early man whose tool kits, artifacts and litter made possible the dating of these beaches and the tracing of the history of the lake (Caton-Thompson & Gardner 1934; Hassan 1986; Wendorf & Schild 1976). The connection which was affected by the Neonile around 9000 B.C. was severed probably by the silting up of the Hawara channel around 8000 B.C. It was re-established some 500 years later during a period of high floods in 7500 B.C. when the lake assumed a level of 18 meters above sea level, after which it fell to a level of 12 meters and then rose to a level of 23 meters. This lake lasted for about 1500 years. Along its shores terminal Paleolithic man of the Fayum B culture lived.

The connection was severed for 800 years between 6000 and 5200 B.C. during which time the depression was deserted and the lake disappeared. The connection was re-established around 5200 B.C. when a lake with a level of 21 meters above sea level developed. This lake lasted for 1300 years. Along its shores Neolithic man of the Fayum A culture lived. The connection of the lake with the Nile was again severed at about 3900 B.C. and continued during the period of lower floods that followed. The connection was resumed during a period of high floods which started at about 3000 B.C. and continued with two periods of interruption (around 2000 and 1200 B.C.) until it was regulated by man in Ptolemaic time. The fluctuations of the lake levels will be discussed in Part II of this book. Figure 1.36 shows the elevations of the successive lakes which formed as a result of the Neonile gaining access to the depression.

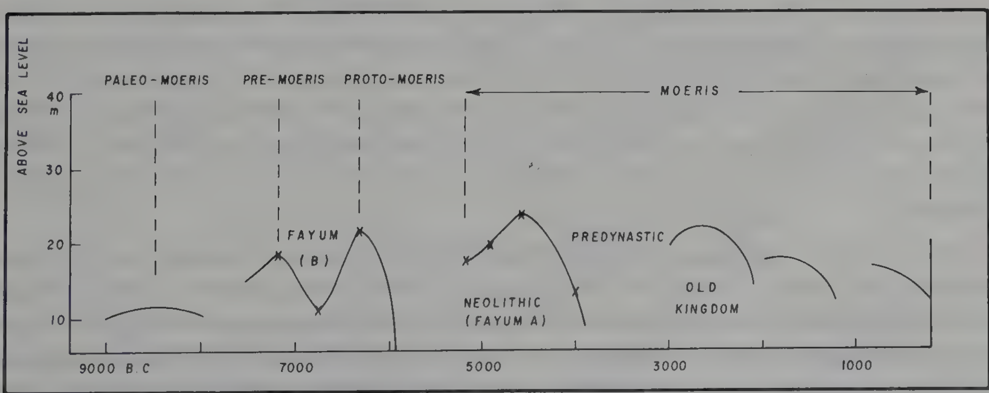

Fig. 1.36. Curve showing fluctuations of lake levels of the Fayum plotted against time.

8

CLIMATE AND THE EVOLUTION OF THE RIVER

The previous chapters have shown that the River Nile has been continuously changing its shape and regimen over time. In addition to the structural conditions which determined its passage and controlled the distribution of land and sea, these changes were determined to a large extent by the climatic fluctuations which must have affected the basin during its life history. The flow of the river fluctuated in response to these variations which determined the precipitation input over the continent of Africa.

The waters of the Nile come from equatorial Africa and the Ethiopian Highlands, both of which today receive their rainfall at the time of "high sun" (Ogallo 1987). The northeastern trades of the Northern Hemisphere and the southeastern trades of the Southern Hemisphere flow toward the low pressure region of the equator from the subtropical high pressure belts located at about latitudes 18° north and south (Fig. 1.37). Where the trades meet is termed the Intertropical Convergence Zone (ITCZ) and that is the region where the rain falls. The yearly north–south–north passage of the sun is accompanied by a similar movement of these major weather systems of the region. Thus close to the equator there are two distinct rainy seasons centered around March–May (long or main rainy season) and October–November (short rainy season) as the ITCZ passes over the region. Farther from the equator most of the rainfall is concentrated within a single rainy season; in the Northern Hemisphere the rains occur in the summer (Fig. 1.38).

This system is modified by the fact that continents tend to be occupied by high pressure areas in winter and low pressure areas in summer. The high pressure system that builds up over the south Atlantic and the Gulf of Guinea in July causes the air movement toward the low pressure centers of the continent producing the monsoons and giving the trades an easterly direction as they move from the south of the equator to the north of the equator. The rainfall in Ethiopia is brought by the southeasterly winds which are driven over the African continent and which , upon reaching the Ethiopian highlands, are forced to rise becoming cooler and depositing their moisture as rainfall from July to September.

The precipitation regimes of the Lake Plateau and the Ethiopian Highlands are, therefore, different. The White Nile is fed from equatorial rains which possess a weak bimodal seasonal distribution, while the Blue Nile is supplied from a seasonally arid regime over the Ethiopian Highlands. The meteorology controlling these two regimes is quite distinct and there seems to be no correlation between the annual precipitation input to these two catchment areas (Hulme 1990). Figure 1.39 plots the precipitation time series

for Uganda and Ethiopia and shows the poor correlatability of the annual precipitation for both areas.

North of the ITCZ belt the summer rain regions pass into deserts. Further north, where the northern part of the Nile Basin is located, lies the Mediterranean climatic belt where the rain falls

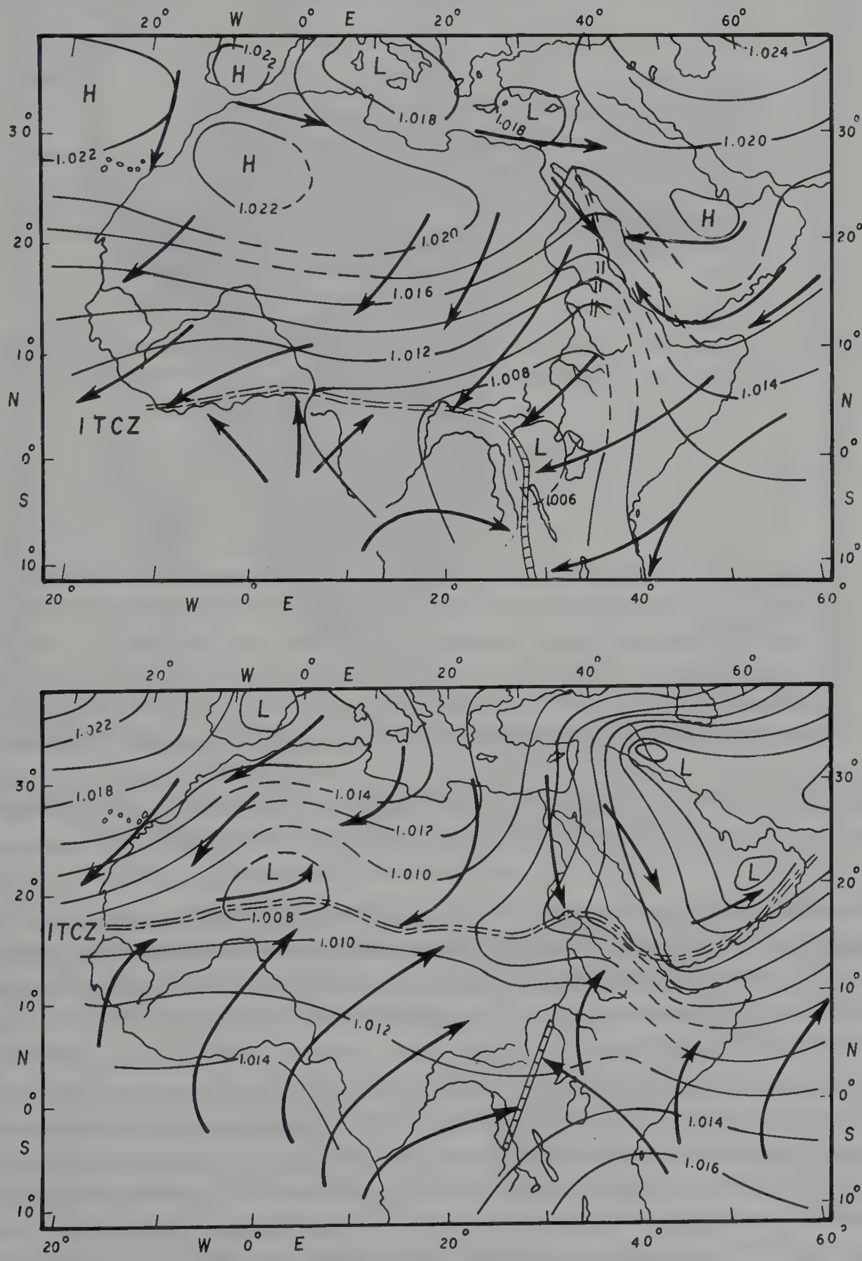

Fig. 1.37. Main daily pressure pattern (mbar) for January (top) and July (bottom) showing movement of the ITCZ in Recent times.

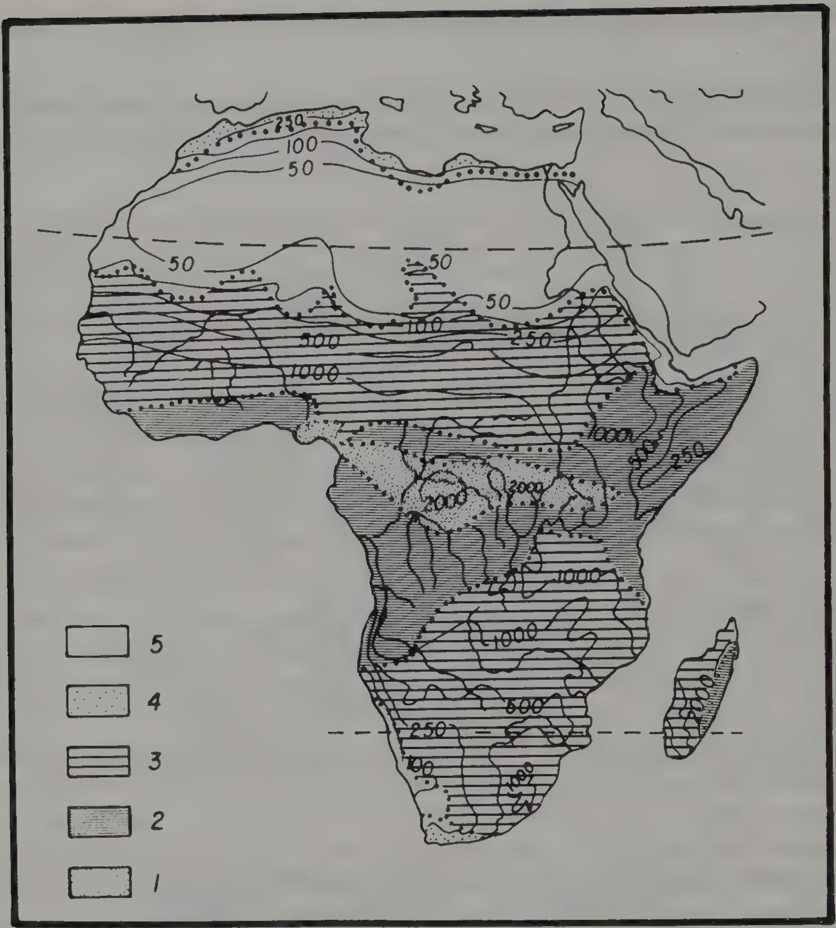

Fig. 1.38. Rainfall in Africa in Recent time: 1. rainfall all year round, 2. two rainy periods, 3. summer rains (one rainy period), 4. winter rains, 5. rare or no rains.

mainly in winter and the summers are hot and dry. This belt is under the influence of the rain-bearing cyclones or cold fronts of the middle latitudes which determine the mean position of the polar front. Under the present climatic regime winter rains are also common along southern Sinai and the coastal mountain chain of the Red Sea to about 17° north where the winters are warm and the summers are hot.

The modern climate, therefore, is under the influence of the mean position of the polar front and the ITCZ. In winter both these systems move south bringing the northern margin of the Nile Basin under the influence of the polar front, which causes rain to fall. In contrast, the headwaters of the Nile receive little rain as the ITCZ moves southward. In the summer the situation is reversed. The polar front moves northward and there is no rain along the Mediterranean coast of Africa. The ITCZ also moves northward across the equator and drops its copious rainfall on the region of the headwaters of the Nile. Figure 1.38 shows the major rainfall belts of present-day Africa.

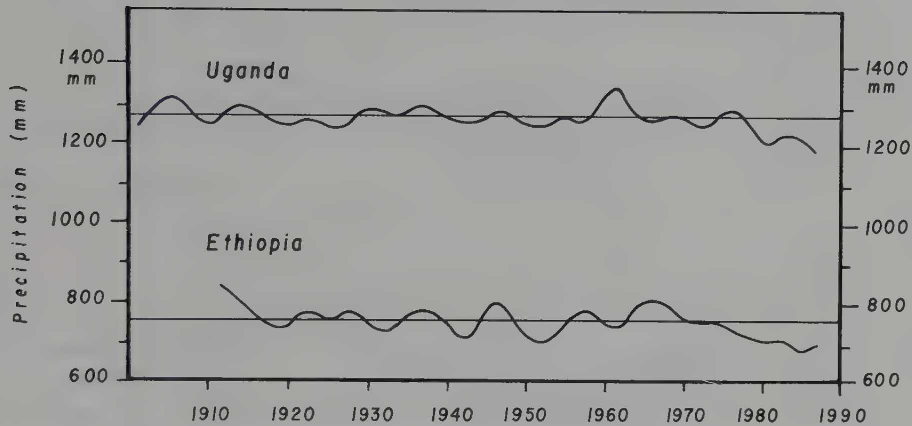

Fig. 1.39. Precipitation time series for Uganda (annual) and Ethiopia (June–August). Horizontal lines indicate median precipitation for the full record (data from Hulme 1990).

8.1. Past Climatic Fluctuations

The reconstruction of past climates is a difficult task and becomes especially so the further we go back in time, since the important factors which determine the climate such as the distribution of land and sea, the height of the mountain chains, the density of vegetative cover and the movements of the ocean currents are either totally unknown or, at best, reconstructed in a very generalized manner. In this chapter we shall restrict our reconstructions to the relatively recent time which has elapsed since the Egyptian Nile assumed an African connection. In attempting to reconstruct the past climates of this relatively short time we have the advantage of eliminating or at least minimizing the effect of some of the many factors which affected the climate such as the distribution of land and sea and the height of mountains which we shall assume have not changed appreciably during that time.

Inspite of the complexity of reconstructing past climates, the climatic changes that have taken place since the middle Pleistocene over the Sahel and the Sahara can be related to the present climatic zones and can be interpreted as a result of the latitudinal shift of the annual mean positions of the polar front and the ITCZ (COHMAP 1988; Kutzbach 1981; Kutzbach & Guetler 1986; Nicholson & Flohn 1980). Historical analogues show latitudinal shifts in the precipitation zones over northeast Africa. These are well represented by plotting the position of the 400 millimeter annual isohyet for a number of recent years (Fig. 1.40). The driest and wettest 30-year periods in the twentieth century producd a latitudinal shift in precipitation zones of between 50 kilometers and 75 kilometers. This movement increased to between 200 kilometers and 300 kilometers when individual years (1929 and 1984) were considered (Hulme 1990). During the Holocene there were even larger shifts; the climatic changes of the past can best be understood within the framework of the hypothesis of latitudinal shifts which we shall adopt in the following discussion.

Fig. 1.40. Position of the 400 millimeter annual isohyet in Central Sudan for various twentieth century years and periods, and for the years 18,000 and 9000 before present (modified after Hulme 1990).

8.1.1. Glacial periods

During the glacial periods, the highly reflective ice sheets, generally cold oceans, and equatorward-extended sea-ice borders resulted in a significantly different climate from that of today. The low temperatures produced by these boundary conditions strengthened the north–south temperature gradient over Eurasia displacing the polar front to parts of north Africa and shifting the ITCZ southward leaving equatorial Africa with considerably lesser rains. The ITCZ barely touched that region during its annual movement. As explained earlier, the climate of the glacial periods was characterized by a greater aridity in the tropics, the shrinkage of the East African and equatorial lakes, the prevalence of semiarid vegetation over large areas of the tropical rain forests and the spread of sand dunes.

Depending upon its extent the southward shift of the polar front during the glacial periods brought about climates with different degrees of humidity over northern Africa. There is evidence that the shift of these fronts varied during the different glacials. During the Riss glaciation, which is correlated with the Abbassian I and II Pluvials (Fig. 1.21), the shift seems to have been further to the south; the tropical summer rain front did not move far enough to the north to affect the Ethiopian Highlands and the Nile's main catchment area had hardly any rain.

The Egyptian Nile lost its African connection. In the meantime the southern shift of the polar front further to the south produced extensive winter rains in northeast Africa and the Red Sea hills up to latitude 14° south; the valley of the Nile was filled with an ephemeral river during the winter months (Fig. 1.41). During this period the ground water reservoirs of the deserts of Egypt were recharged and the desert became habitable. Early Paleolithic man made a grand appearance; his remains are found in many parts of the desert as well as in the Nile Valley.

During the last glacial (the Wurm), the shift of the fronts to the south did not seem to have been as pronounced as during the earlier glacials. There were enough rains in the Ethiopian Highlands to activate the seasonal beta and gamma Neoniles. Similarly, the shift of the polar front to the south did not produce significant rains in Egypt which must have been extremely dry; there is no evidence of human habitation in the deserts of Egypt which seem to have been totally abandoned during the last glacial. Figure 1.41 is a hypothetical mean atmospheric circulation scheme over Africa during the last glacial showing the presumed position of the ITCZ and the polar front which adversely affected the precipitation levels over most of Africa.

During the Mindel glaciation, which is correlated with the Saharan Pluvial (Fig. 1.21), the southward shift of the ITCZ and the polar front was such that there were sufficient rains at the headwaters of the Nile to bring to Egypt a river, albeit with a smaller discharge. At the same time, there was an ample season of winter rains all over Egypt to contribute additional water to the Nile during the winter season, to recharge the ground water reservoirs of the desert and to make it a habitable place. Archeological sites belonging to the Middle Paleolithic, which is associated with the Saharan Pluvial, are described from many places in the Sahara and the deserts beyond the Nile.

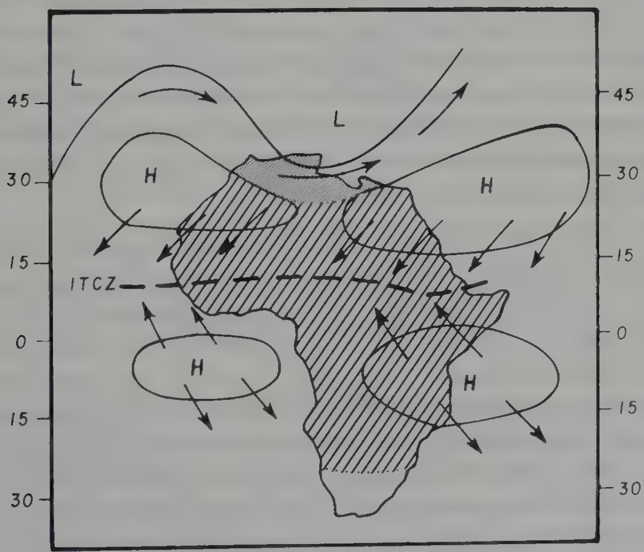

Fig. 1.41. Hypothetical mean atmospheric circulation scheme over Africa during the last glacial; more humid than today areas are shaded, drier than today areas are hachured (modified after Nicholson and Flohn 1980).

It must be remembered that the climatic model given here is a comprehensive framework for the large-scale changes of climate. It does not reflect the great variability and complexity of these climatic episodes. For instance, there is evidence that the pluvial phases were not uninterrupted and that within each phase there were climatic oscillations. The rains of the Middle Paleolithic Saharan Pluvial were interspersed with arid intervals. This is not only indicated by the erratic Nile of this phase but also by the fact that deep in the south Western Desert of Egypt, in the Bir Sahara–Tarfawi area, lakes developed and dried up at least five times in the same place. A series of five if not six successive lakes developed during the Saharan Pluvial in that area according to the work of Wendorf and Schild (Wendorf & Schild 1980). Each lacustrine event had numerous Middle Paleolithic settlements.

8.1.2. Post-last glacial times

Two thousand years after the beginning of the retreat of the ice of the last glacial a general warming trend occurred at about 12,500 before present. This was accompanied by an increase in rainfall in equatorial Africa, the return of forest vegetation and the rise of lake levels. As we have noted in our discussion of the history of the modern river, the waters of the Nile increased considerably at the beginning of the warming period as a result of the supply from the Equatorial Lake Plateau; the first indication of an increased water supply from the Ethiopian Highlands came about 2500 years later. It seems that the period 12,500-10,000 years before present affected only the regions which were watered by airflows from the Atlantic; there is no evidence of significant rains for the areas surrounding the Indian Ocean which seems to have warmed up at a considerably later time than the Atlantic (Street & Grove 1979).

About 10,000 before present the ITCZ seems to have moved northward (Fig. 1.42) bringing rains to the Ethiopian Highlands and to large parts of the Sahel and southern Sahara (the Holocene or Nabtian Wet Phase). The Nile flowed copiously as the region of its headwaters fell within the ITCZ. As this wetting front moved northward over time, it brought rains to northern Sudan before southern Egypt and studded these two areas with lakes. It has now been proven that the southern lakes of the eastern Sahara are older than the northern lakes, giving further support to the concept of a northward migration of the monsoons over time (Haynes 1987). This wet phase was interrupted by short periods of aridity which may be ascribed to reduced evaporation in the Atlantic (Degens & Spitzy 1983).

The Holocene (Nabtian) Wet Phase was the result of the northward movement of the ITCZ; consequently the rains it brought to southern Egypt and northern Sudan were summer rains. In contrast, the rains of the earlier pluvials were winter rains resulting from the southward movement of the polar front. During the Holocene (Nabtian) Wet Phase the rains, therefore, were concentrated in the southern parts of Egypt. In contrast, the northern part was arid. This explains the poorly developed drainage lines, the absence of playa deposits, the poor to non-existent archeological sites from Terminal Paleolithic–Neolithic time and the preservation of old salt deposits in the Qattara depression. The Siwa archeological sites (Hassan 1978) and those from the Sitra region (southern rim of the Qattara depression), both from the fifth millenium B.C., were dependent, as at present, on ground water sources (Cziesla 1989). The rarity of archeological sites in northern Egypt from the preceding pluvials, on the other hand, may be due to the fact that they were buried, destroyed or eroded away.

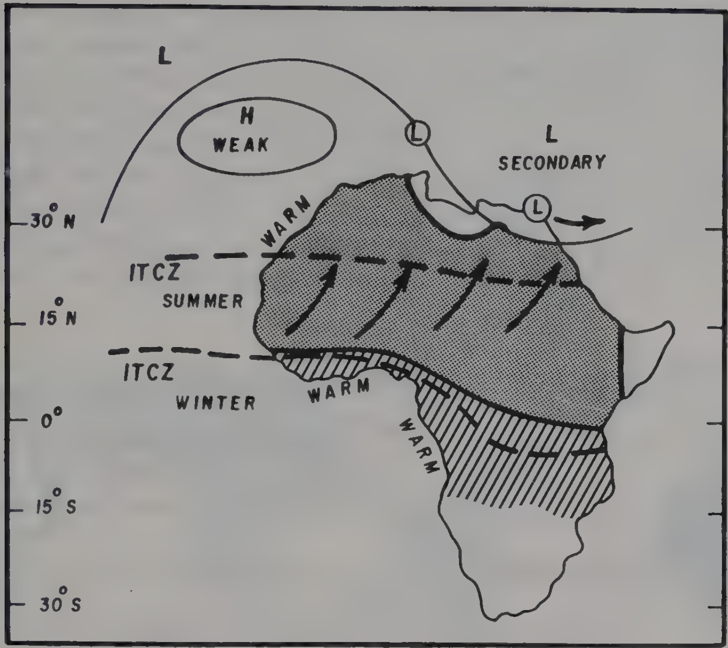

Fig. 1.42. Hypothetical mean atmospheric circulation scheme over Africa during the Holocene (Nabtian) Wet Phase; areas more humid than today are shaded; areas drier than today are hachured (after Nicholson and Flohn 1980).

8.2. Forcing Factors and the Question of Periodicity

In attempting to understand the factors which have determined the past history of the Neonile and which will determine its future, the question of scale becomes all important, for the forcing factors which determine both the precipitation input and the flow of the river operate on distinctive scales. Long-term forcing factors include changes related to such astronomical variations as the eccentricity of the earth's orbit (which operates over a 100,000 year cycle), obliquity of the ecliptic (41,000 year cycle), precession of the equinoxes (23,000 year cycle), sol ar activity and other causes. Figure 1.43 depicts these orbital forcing factors which have come to be known as the Milankovitch cycles after the scientist who was the first to recognize their effect on the climate.

These changes in the earth's orbit and spin axis control the small changes in the seasonal and latitudinal distribution of solar energy received by the earth, and hence determined the length and periodicity of the glacial cycles of the past two million years. These long-term factors were probably also responsible for the larger cycles which made or broke the connection of the Egyptian Neonile with its African sources during the past 400,000 years. The beta and gamma seasonal Neoniles developed during the last glacial which was determined by orbital forcing. The modern Nile was born with the retreat of the ice of this glacial when a considerably wetter climate prevailed over the headwaters of the Nile as well as

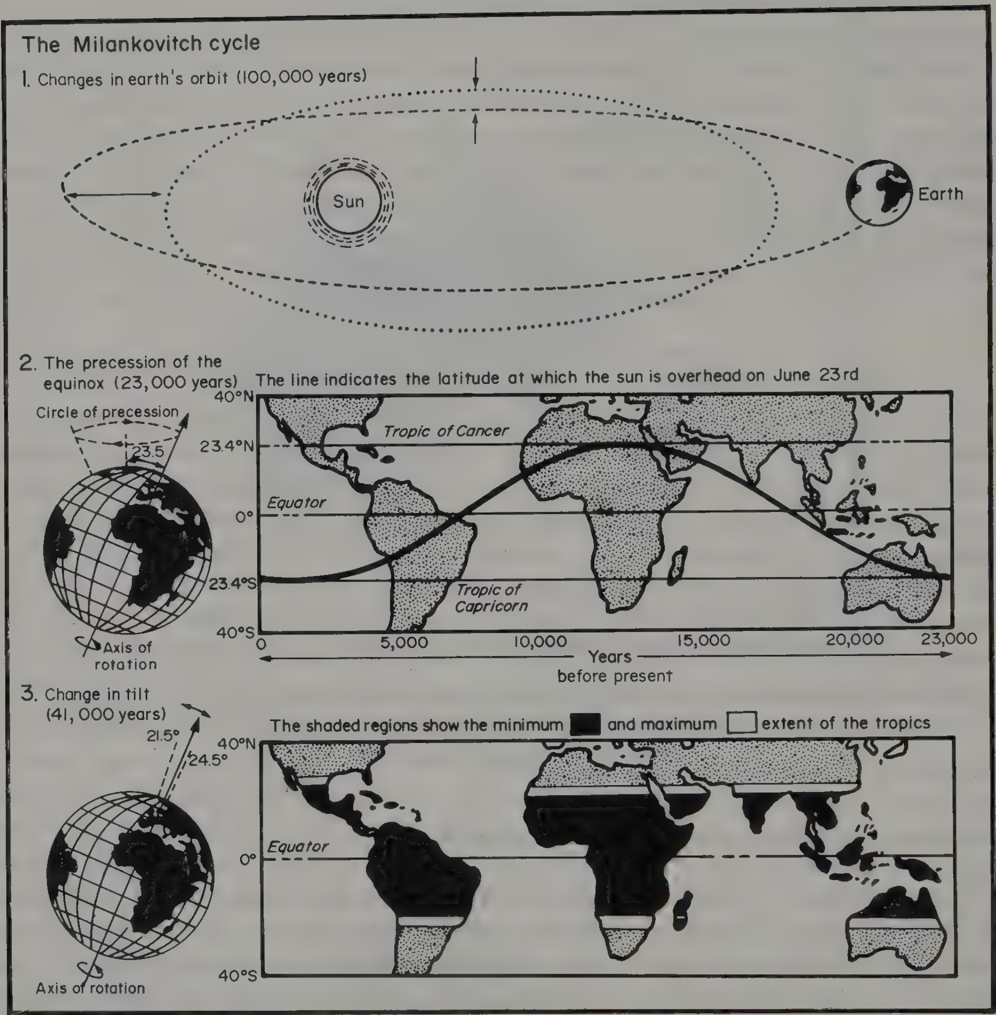

Fig. 1.43. The Milankovitch cycles (1990 The Economist Newspaper Group, Inc.).

large parts of the Sahara. With sources from both the equatorial lakes and the Ethiopian Highlands the river assumed a perennial character. As long as it lasted the rainfall over the Sahara enlarged the catchment area of the river and increased its flow. The precession cycle which produced this situation is coming to a close, probably some 5000 years away. Therefore, the long-term future of the modern river is not bright. It will dry up as many rivers before it have dried up. This prediction should be taken only as an intellectual exercise for it will certainly have no effect on the lives of this and many future generations. Cycles of thousands of years span hundreds of generations which puts them beyond the scope of anticipation or concern.

The immediate future of the river, which should concern us most, is influenced by the forcing factors which act on shorter time scales. There is a hierarchy of these which act on decadal,

annual or seasonal scales. These include, among many others, land-cover changes, patterns of ocean circulation, concentration of greenhouse gases, shifts in the ITCZ and the El Nino Southern Oscillation (ENSO). Many of these factors are interdependent. Thus, for example, the patterns of ocean circulation and the location of the ITCZ which determine tropical rainfall regimes are modified to a large extent by the ENSO events. Attempts to reconstruct past climates or to forecast long-term future climates have been made using General Circulation Models in which the parameters of these factors or their historical analogues have been used. Examples of these attempts are the climatic scenarios proposed for Africa during the Holocene Pluvial (COHMAP 1988) and the latter part of the Pleistocene (CLIMAP 1976).

PART II

THE HYDROLOGY OF THE RIVER NILE

1

INTRODUCTION

> "When the Nile overflows, the whole country is converted into a sea, and the towns, which alone remain above water, look like the islands of the Aegean", Herodotus (ca. 450 B.C.).

This part deals with the hydrology of the river the systematic study of which started at the beginning of the nineteenth century with the rise of the modern state in Egypt. The introduction of cash crops and the expansion of agriculture necessitated the more efficient use of the waters of the Nile which was possible only through a better understanding of the geography and hydrology of the river. Thus began an age of discovery and study that made the Nile one of the best monitored rivers in the world.

Throughout most of their history the Egyptians viewed the Nile as an integral part of the order of the universe; as the sun rises and sets every day so does the Nile rise and ebb regularly every year, a phenomenon which was monitored with awe and celebrated with ritual for many centuries. The sources of the waters of the Nile and the reason behind its yearly increase were unknown and were wrapped up in mystery. Inspite of the high literacy of Ancient Egypt and the great importance of the waters of the Nile for its survival, no one seemed to have succeeded in penetrating the river to its sources. It was only in the nineteenth century, in fact as late as 1937, that the most southerly source of the Nile was discovered. This discovery was commemorated by the inscription of the words "*Caput Nili* " on a small hill to the north of Rutana village. This discovery was at the foothills of northern Burundi about 4° to the south of the Equator where the Luvironza River joins the Nlavarongo River. Both rivers form the Ruvuvu tributary of the River Kagera which flows into Lake Victoria.

2

RHYTHM AND RITUAL OF THE NILE

> "The festival of the archangel Michael has given rise to a fable, which is firmly believed, as well as by the Turks, as by the Cophts and other Christians of this country, viz: That the angel on that day, throws a drop of water of such fermenting quality into the river, that it causes it to rise to such a height, as to overflow all the country," J. Atens (1801). *Observations on the manners and customs of the Egyptians*. Dublin: 78.

The immense fertility of the land of Egypt is due entirely to the annual inundation of the Nile which, regulated by an elaborate system of canals and dams, was distributed over the fields, renewing the soil year by year with a fresh deposit of mud. Prior to the construction of the great irrigation works of the nineteenth and twentieth centuries in Egypt and the Sudan, the inundation level of the Nile in these two countries used to pass through an exceedingly regular cycle which was always watched by the inhabitants with great anxiety; for if it fell short of or exceeded a certain height, death and famine or overflooding and destruction were the inevitable consequences. After the beginning of the rainy season in Ethiopia the river started to rise early in June and gradually swelled to its maximum by the end of September. The country was then submerged and presented the appearance of a sea of turbid water from which the towns and villages, built on higher ground, rose like islands. For about a month the flood remained nearly stationary, then subsided more and more rapidly till, by December or January, the river returned to its ordinary bed. With the approach of the summer the level of the water continued to fall. In the early days of June the Nile was reduced to half its ordinary breadth; and Egypt, scorched by the sun and blasted by the wind from the Sahara, seemed a mere continuation of the desert.

The following table shows the dates, the amount of the rise of the water of the river and the volume of water carried at Aswan, Cairo and the delta in an average year in the latter part of the nineteenth century. In Aswan, between the end of May and the end of July, the water rose about 8.25 meters and the volume of water carried increased fifteen fold. There was a lag of 12 days between Aswan and Cairo in May and 6 days in September when the flow was faster, and a lag of 10 and 3 days between Cairo and the north delta.

The Nile is one of the most predictable rivers of the world. Its flood is seldom sudden or abrupt. It rises and falls with regular and stately precision bringing to Egypt quantities of water that are rarely excessively destructive and that come within a range of time that makes possible the fecundity of the land of Egypt. Of 820 floods recorded on the Roda Nilometer, south of Cairo, between the seventh and fifteenth centuries, 73 percent were "normal" floods that reached a height which inundated all the basins and subsided at the proper time for sowing. Twenty two percent of the floods were low; 7 percent never reached or had a late plenitude (the height which

	Aswan		Cairo		Delta	
	Rise m	Volume 10^3 m^3/day	Rise m	Volume 10^3 m^3/day	Rise m	Volume 10^3 m^3/day
End May	0	50				
10 June			0	45		
15 June					0	40
20 June	5	100				
Early July			3	90		
10 July					2.5	80
15 July	7	200				
20 July			5	18		
22 July					3.5	160
30 July	8.2	75				
5–10 Sept.			6.5	675		
8–11 Sept.					4	600
End Sept.	7.5					

allowed the inundation of the fields) and 15 percent inundated only part of the cultivable land. Five percent of the floods were destructively high.

The average duration of the flood was about 110 days. Of the 46 floods of the years 1890–1935 it was less than 75 days in four years and more than 125 days in twelve years. The maximum duration of the flood was in 1894 when it lasted for 162 days between May 17 and October 26. Out of 207 years in which both the minimum and maximum levels were recorded, the rise of the Nile began in the month of June approximately 75 percent of the time, in the month of May 10 percent of the time and in the month of July 15 percent of the time. It never occurred before May 17 or after July 6.

The maximum rise of the river occurred in the latter part of September and the early part of October in approximately 87 percent of the time. In 5 percent of the time the maximum rise occurred in November. There was no record of a maximum rise before August 7 or after November 27.

Until recently the beginning of the rise of the Nile was celebrated in Egypt on the night of June 17, which corresponds to Ba'una 12 of the Coptic calendar, the so-called "Leylet el-Nuktah" (or the Night of the Drop), as it was believed that a miraculous drop then fell into the Nile and caused it to rise. It is possible that the origin of this belief goes back to the ancient Egyptian festival celebrating the rise of the river which the ancient Egyptians believed swelled as Isis shed tears for the death of Osiris. The Copts of modern Egypt celebrate Ba'una 12 as St. Michael's day on which date the Archangel Michael is believed to have asked the Lord for the rise of the Nile.

From June 17 the rise of the Nile was watched daily and used to be proclaimed in the streets of Cairo by the "crier of the Nile" (Munadee El Nil). When the Nile reached a level of 16 cubits

it became the signal for opening the feeder canals to inundate the fields. This was the occasion of a formal and popular ceremony in Cairo to celebrate the plenitude or fulfillment (Wafa'a) of the Nile.

The level of 16 cubits was the level most favorable for the inundation of the basin lands of Egypt during Graeco-Roman time and also at the beginning of the Arab period when measurements of flood levels were taken at the then newly built Cairo Nilometer at the southern tip of the Roda Island opposite Old Cairo. In the seventh century a "good" flood averaged 6.4 meters above the average low water level of 1.9 meters (above the floor of the gauge). This level of the flood would be 8.3 meters above the floor of the gauge (or 16.45 meters above sea level) and would mark 16 cubits on the gauge of that time. The level 16 is mentioned by many classic writers as the level most convenient for the inundation of the land of Egypt. Pliny (first century A.D.) states that "with a rise of 12 cubits it (the Province of Memphis) senses the onset of starvation and even with 13 cubits it is still hungry. But 14 brings joyfulness, 15 freedom from care and 16 sheer delight". The figure 16 is also mentioned by Amr, in a letter he sent to Caliph Omar after he had entered Egypt in 640 A.D., as the optimum level for prosperity: "I have found that Egypt needs a minimum flood level of 14 cubits so that its people do not starve, and a level of 16 cubits so that they prosper and store a year's supply beyond their needs; and that the frightening extremes of deficiency and excess, or drought and overflooding, are 12 and 18 cubits".

In Graeco-Roman times the figure 16 and the flood waters of the Nile became symbols of life and prosperity not only in Egypt but also throughout the Mediterranean region where a cult of the flood waters of the Nile developed (Bonneau 1964). During Trajan's time, medals were minted carrying the Nile statue with an angel pointing with his finger to the numeral XVI. In many temples of Ancient Rome stood statues of the Nile. Perhaps the most famous of these is the colossal marble statue of the Nile, housed in the Vatican Museum; it stood in antiquity in the Serapis and Isis temple at the present site of the church of Santa Maria sopra Minerva (Fig. 2.1). The river, identified by the sphinx and the crocodile as the Nile, is represented by a reclining male figure with long hair and beard. In his arm he holds a cornucopia with flowers and fruit as a benediction. The 16 boys, each having a height of one cubit, rest at various levels on the monument.

Since the building of the nilometer in the seventh century A.D., the bed and the flood plain of the river rose as a result of the deposition of the silt which the river carried every year. This resulted in the gradual rise of the effective level at which the inundation of the land was at its optimum. In the mid-nineteenth century, when a new scale for the nilometer was installed, the effective level was higher by 2.5 meters. It was reached on the new scale of the nilometer at the level of cubit 22 (18.97 meters above sea level). Inspite of that, the figure 16 continued until recent time to be the figure at which the formal ceremony for the "plenitude" of the Nile took place, although this level did not flood except the low lands; the middle and high lands were flooded at a later date, the first on the Neirouz (beginning of the Coptic calendar, September 9) and the latter on Holy Cross Day (September 27) when the effective level was reached (Ghaleb 1951).

The cutting of the dams and the admission of the water into the canals and fields were great events in the Egyptian year. In Cairo the cutting usually took place between August 6 and 16 and, until recently, was attended by ceremonies which were probably handed over from antiquity. During this celebration an earthen dam, which was constructed before or soon after

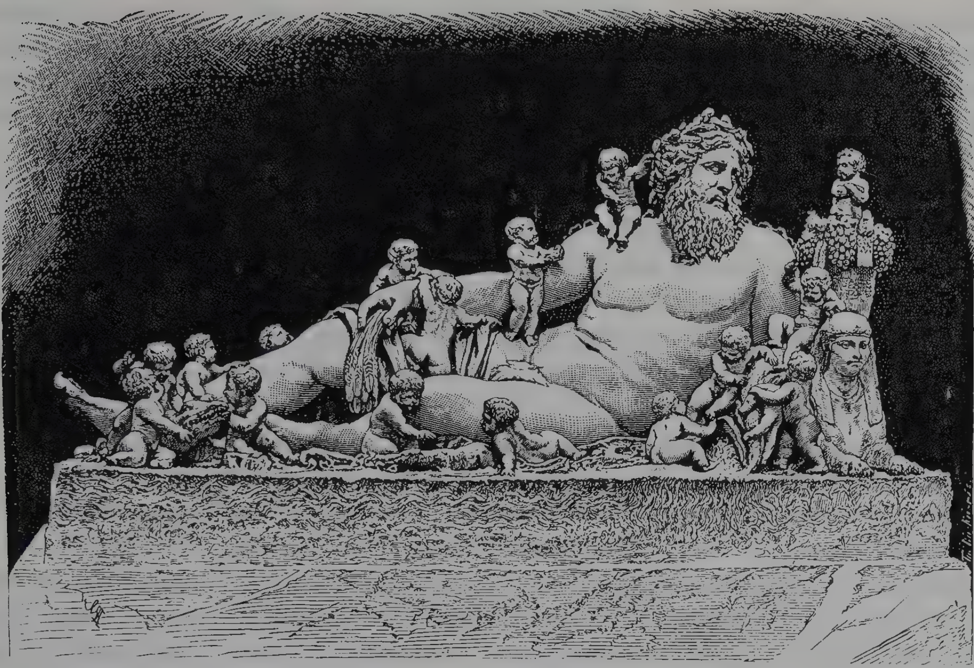

Fig. 2.1. Statue of the Nile, Vatican Museum.

the Nile began to rise at the entrance of the Khalig canal, was cut. This canal used to branch off Old Cairo (Fig. 1.28) until its filling up in the latter years of the nineteenth century. Near its entrance the canal was crossed by the earthen dam which was very broad at the bottom and diminishing in breadth upward.

In front of the earthen dam on the side of the river a truncated cone of earth, called the 'aroosa (bride), was built and on top of which maize (Doora) was sown. This "bride" was commonly washed by the rising tide a week or so before the cutting of the dam. Tradition has it that the washing of this earthern "bride" replaced an old custom in which a young virgin decked in gay apparel was thrown in the river as a sacrifice to obtain a plentiful inundation. Whether that was so or not, the intention of the ceremony was to marry the river, conceived as a male power, to his bride the cornland, which was soon to be fertilized by his water. The ceremony was a charm to ensure the growth of the crops. In more recent times money used to be thrown into the canal on this occasion, and the populace dived into the water after it.

In Ancient Egypt a large number of statues and reliefs show that the flood was deified and incarnated in the god Hapi who remained for a long time a secondary god commanded by other gods, especially the God Osiris (Myriam Wissa, personal communication). The ritual celebrating the God Osiris, who personified the resurrected life force as manifested by the ever recurring flood and vegetation, was practiced with great pomp by the State and public. The origin of the Osiris myth is unknown. The legend goes that Osiris was killed and dismembered by his evil brother Setekh. Through the persistence of his faithful wife, Isis, and the courage of his son, Horus, Osiris was brought back to life and his death was avenged. Through the centuries Osiris

became the symbol of life persisting through death and was identified as the god of the dead. Since corn and vegetation die and come back to life every year with the Nile flood, he became the personification of the renewal of the flood and the rebirth of vegetable life. From the death and resurrection of the great god the Egyptians drew their support in this life and their hope in a life eternal.

Inscriptions on the Dendera Temple (Fig. 2.2) exhibit in a series of scenes the dead god lying swathed as a mummy on his bier; then he gradually raises himself up until he stands erect between the guardian wings of the faithful Isis who stands behind him, while a male figure holds up before his eyes the ancient Egyptian cross (the Ankh) which symbolizes life.

The next great event in the agricultural year in Egypt was the sowing of the seed in the late fall after the water of the inundation had retreated from the fields. This seemed to have been a solemn event which the ancient Egyptian farmer celebrated by a charm that was believed to ensure the growth of the crops. The charm took the form of an effigy of the God Osiris which was moulded of earth and corn and was buried in the ground with funeral rites, so that dying there he might come to life again with the new sprouts. Effigies made of earth and corn and bundled as mummies were found in many tombs of ancient Egypt.

In the temple of Isis at Philae a series of presentations on the walls of the chamber dedicated to Osiris, shows the dead body of Osiris with stalks of corn springing from it, while a priest waters the stalks from a pitcher which he holds in his hand. The accompanying inscription sets forth that "this is the form of whom one may not name, Osiris of the mysteries, who springs from

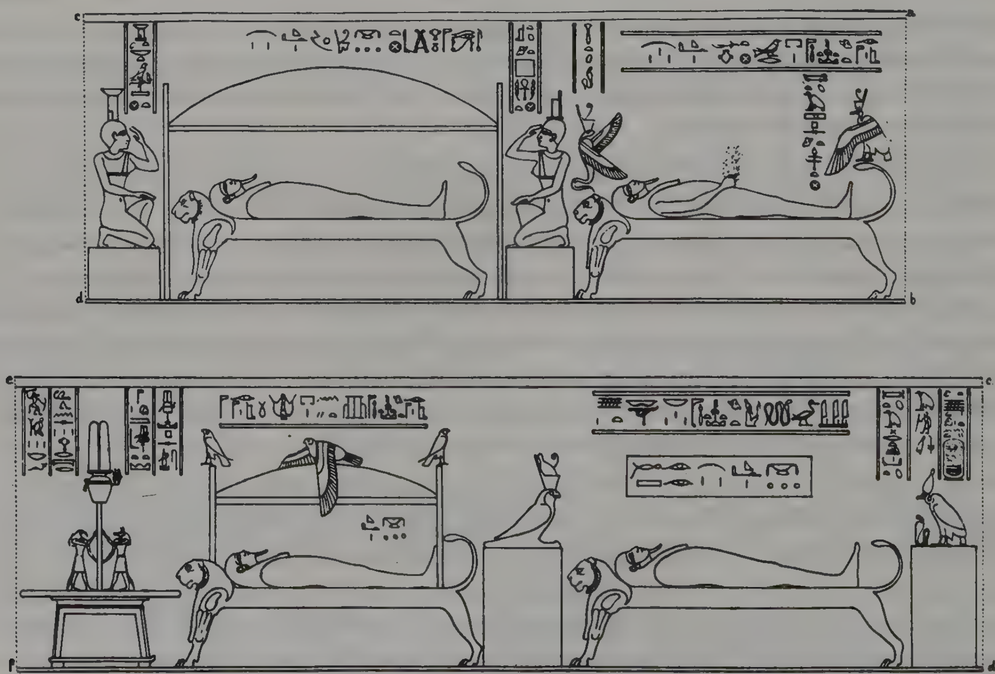

Fig. 2.2. Osiris rising from the dead, from inscriptions on the Denderah temple (after Mariette 1875).

the returning waters." The picture and the words seem to leave no doubt that Osiris was here conceived and represented as a personification of the corn which springs from the fields after they have been fertilized by the inundation. This, according to the inscription, was the kernel of the mysteries, the innermost secret revealed to the initiated. The sprouting of the grain from the effigies of Osiris made of earth and corn and buried during the festival of sowing is hailed as an omen, or rather as the cause, of the growth of the crops. The corn-god produced the corn from himself; he gave his own body to feed the people; he died that they may live.

The aspect of Osiris as the ruler and god of the dead was as important as his function of making the earth bring forth its fruits in due season. He was believed to raise the dead from dust to life eternal, as he caused the seed to spring from the ground. The corn-stuffed effigies of Osiris found in Egyptian tombs furnish an eloquent proof; they were an emblem and an instrument of resurrection. From the sprouting of the grain came the belief in human immortality.

Thus the festival of Osiris was also an occasion to commemorate all the dead. A great feature of the festival was the nocturnal illumination of the outside of the houses with rows of oil-lamps which burnt all night long. The illumination of the houses for one night of the year suggests that the festival may have been a commemoration not merely of the dead Osiris but of the dead in general. It was a widespread belief that the souls of the dead revisit their old homes on one night of the year; and on that solemn occasion people prepared for the reception of the ghosts by laying out food for them to eat and lighting lamps to guide them on their dark road from and to the grave. It is possible that the Christian All Souls' Day, which also falls in November, has its origin in this custom.

3

IN SEARCH OF THE SOURCES OF THE NILE

> "The Nile has two special features: one is the extent of its reach since we do not know of any other river in the inhabited world that is longer, for its beginnings are springs that well from the mountain of the Moon which is purported to be 11° south of the Equator, two is its increase which takes place when other rivers dry up for it begins to increase when the long days start to end and reaches its maximum with the autumn equinox when the canals are opened to flood the lands" Abdullatif El-Baghdadi ca. 1200 A.D.

Prior to the great age of discovery of the nineteenth century the geography of the Nile Basin was shrouded in mystery. Inspite of the fact that the southern boundary of Egypt for a long time was at Aswan, beyond which navigation became difficult, interest in controlling Nubia and penetrating Africa were important strategic goals of early Egypt. Predynastic burials in Nubia attest to the fact that this land was inhabited by Egyptians from the earliest of times. For a long period during the middle and new Kingdoms of Ancient Egypt Nubia was integrated into the Egyptian Empire which extended at one time up to Khartoum. Missions sent into Africa also show the interest of Ancient Egypt in expanding its trade and going beyond its boundaries. Inscriptions carved upon the walls of the tombs of several princes of Elephantine opposite Aswan describe expeditions sent to Nubia during the latter years of the Old Kingdom. Perhaps the most informative of these is that inscribed on the tomb walls of Harkhuf which describes the expeditions sent by Pharaohs Mer-en-ra and Pepi II (Dynasty VI about 2300–2200 B.C.) to the land of "Yam". From his third journey, Harkhuf "returned with 300 asses, laden with incense, ebony, Heknu-oil, leopard skins, elephant tusks, throwing sticks and all goodly produce", and from a later mission with a pigmy from the Sudan for the youthful Pepi II. The land of Yam, the end point of Harkhuf's journeyings, was probably situated in Kordofan (Murray 1951).

One of the earliest attempts to assemble the geographical knowledge about the Nile was that of Claudius Ptolemy, the Library of Alexandria scholar who authored the two great classics, the Almagest and the *Geographike Syntax* , which remained the standard references in astronomy and geography respectively for more than 1000 years after their writing. The Nile map included in the Atlas (Fig. 2.3), which accompanied the eight-volume *Geographike*, was the standard map of the river until the nineteenth century. It was reproduced in different forms by European and Arab scholars of medieval times. The part of the map depicting the river beyond Nubia was based on hearsay. It shows the river originating from two lakes to the south of the Equator which were said to be fed from the melting snow of an east–west mountain range, the "Mountains of the Moon". The two lakes are later referred to in several medieval writings as the Lake of Crocodiles and the Lake of Cataracts. The two rivers emanating from the two lakes are shown in Ptolémy's map to unite at latitude 2° North to form the River Nile which at latitude 12° North

Fig. 2.3. Map of the Nile after Ptolemy.

receives the tributary of Astapus (Blue Nile) shown to originate from the lake Coloe (Tana). North of that the river is shown to receive the tributary Astaboras (Atbara) from the southeast.

In medieval time the Arabs settled on the east coast of Africa, penetrated the continent and knew about the Equatorial lakes which they connected with the sources of the Nile, although

no traveller had ever made the trip from these lakes to the lower reaches of the river. El-Idrisi (1154 A.D.) extended the notion further by surmising that these lakes were not only the source of the Nile but also of the River Niger. The idea that the Nile and the Niger were connected was so deeply ingrained that when the Portuguese set foot in the Gulf of Senegal some 300 years later in 1445 A.D. they thought that the Senegal River was but a tributary of the Nile.

About Ethiopia much must have been known in Ancient Egypt. Trading missions channeled the Red Sea from the earliest history of Ancient Egypt reaching as far as the land of Punt (? modern Somalia). By New Kingdom times the Egyptians had trading posts on the Red Sea coast which were later extended during Ptolemaic times into Ethiopia and the capital Axum. Christianity entered Ethiopia in the year 330 A.D. at the hands of Frumentius, an Egyptian merchant from Alexandria, and remained a bond between the two countries even during the Arab reign and the introduction of Islam. Although no one had ever furrowed the deep gorges of the Blue Nile or the Atbara to their source until relatively recent time, the Egyptians knew that the flood of the river came from Ethiopia. They frequently sent messengers to its kings during years of low flood. In 1106 A.D. the seventh of the Fatimid Caliphs, El-Musta'ala Bellah, sent the Coptic Patriarch loaded with gifts to the King of Ethiopia to ask him to allow the flood to flow into Egypt.

The great circum-navigational voyages of the Portuguese during the fifteenth century led to the discovery in 1488 of an alternate route for the Indian trade by way of the the Cape of Good Hope. Before then this trade had been channeled through Egypt. The loss of that trade cost Egypt its prosperity. But for the Portuguese it was a time for expanding their trade, settling in many parts along the coasts of Africa and establishing relations with many of its countries. Ethiopia, which had become partly isolated after its retreat from Yemen in 575 A.D. and totally isolated after the Arab conquest of the surrounding region, welcomed the Portuguese. In 1490 a Portuguese mission under the leadership of Pedro de Covilham established presence in Ethiopia. This presence was soon followed by a military mission which was invited by the Emperor of Ethiopia to repulse the invasion to which Ethiopia had been subjected between 1528 and 1540 by the Somali leader Ahmed Garran. From that time and until their eviction in 1633 by order of the Emperor, the Portuguese became influential and were allowed to travel in Ethiopia. Of those who recorded their observations, Jesuit Pedro Paez may be singled out for his description of the source of the Blue Nile during his visit to that area with the Emperor in 1618. Other important missionaries were Jeronimo Lobo and Emanuel D'Almeida. The descriptions of these missionaries must have been so vivid and detailed that D'Anville, the famous French geographer, was able upon their basis to raise a map of Ethiopia and the Blue Nile some 150 years later. This map was published in D'Anville's classic work "*Mémoire et abrégè de géographie ancienne et générale*".

After the exit of the Portuguese Jesuits, Ethiopia was not visited by any European for about 100 years with the exception of Poncet, the French surgeon, who in 1701 went to Gondar by way of Cairo and Sennar to treat the Emperor. In 1768 Bruce, the English explorer, started his memorable voyage to Ethiopia from Cairo in search of the sources of the Nile. From there he proceeded to Quseir, then by sea to Jedah and Musawa. He then crossed the coastal plain and entered the high mountains of Ethiopia passing by Adwa, Axum and Gondar, where Emperor Michael of Ethiopia resided. Bruce was able to befriend the emperor, visit the sources of the Blue Nile, tarvel around Lake Tana and cross the Tissisat Falls. He then returned home in 1773 by

way of the Blue Nile up to its confluence with the White Nile and from there to Cairo. Bruce believed that the Blue Nile was the main source of the river and that the White Nile was a tributary of it. Upon his return to England he found that D'Anville had already published a map of the sources of the Blue Nile and that his own reports on the unfamiliar customs and culture of the peoples of Ethiopia had been received with a great deal of skepticism. This made him hesitate to publish his memoirs which, however, finally appeared in 1790, seventeen years after his return to England, in eight volumes "*Travels to discover the source of the Nile in the years 1768–1773*". The story of the discovery of the Blue Nile is given in Moorehead (1962).

Until the middle of the nineteenth century no one had been able to penetrate the Nile beyond the Sudd swamps not only because of the difficulty of navigating the stream but also because of the prevalence of disease which made survival for man and beast difficult. It is to the credit of Mohamed Ali, the founder of modern Egypt, that the Sudan became accessible and that the Nile sources began to be systematically studied. In 1820 he embarked on a military campaign to ensure his control over the sources of the Nile the waters of which became important with the expansion of agriculture and the introduction of the cultivation of cotton in Egypt. After the opening up of the Sudan Mohamed Ali sent a series of expeditions under the command of Salim Qapudan to discover the sources of the White Nile. The first expedition, which left Khartoum in 1839, passed the mouth of the Sobat, on to Lake No and proceeded in Bahr el-Gebel up to latitude 6° 30' near Bor. The second and third expeditions were carried out between 1840 and 1842. They reached Rejaf at latitude 4° 42'. The expeditions could not proceed any further south but did put an end to the view that the sources of the White Nile were in the west. This view was so prevalent that all travellers and cartographers of the early nineteenth century showed the sources of the Nile to the west. The map which accompanied Burckhardts book "*Travels in Nubia*" published in 1813 also showed the White Nile coming from the west (Fig. 2.4).

The originals of the reports of these missions are housed in the Abdin Palace, Cairo; a French translation of some of these reports was published in the B*ulletin Sociéte Géographique de Paris,* 2eme serie, volumes 17 & 18, 1842. Further accounts of these expeditions are given in the works of the experts who accompanied them such as G. Thibault (1847) and F. Werne (1848).

The Egyptian expeditions also opened up this part of the Sudan for trading posts and eventually missionary activity. They also made possible the exploration of the Bahr el-Ghazal region which was carried out by Petherick (1863–1865), Miss Tinne and later on by Schweinfurth (1868–1871). Schweinfurth's book (1874) on his adventures in the heart of Africa became a classic, was translated to many languages and printed many times.

While the Egyptians were deeply engaged in exploring and expanding their influence on the sources of the Nile, the rising imperial powers of Europe were eyeing the virgin lands of Africa. In 1858 the English explorers J.H. Speke and R. Burton approached the Nile from East Africa and reached Lake Tanganikya and then returned back half way where Burton fell ill and could not continue the trip. Speke went on, reaching the city of Moanza on the southern shores of Lake Victoria which he called Lake Nyanza and which he guessed to be the source of the Nile, although he had not traveled around it. Upon his return to England he published a paper claiming to have discovered the sources of the Nile. He was granted funds by the Royal Geographical Society to return to Africa. In 1860 Speke accompanied by J. A. Grant reached the capital of Buganda on the northern shores of Lake Victoria, which Speke assumed to be the same Lake Nyanza he had seen on his previous expedition. On this trip Speke and Grant were able to see

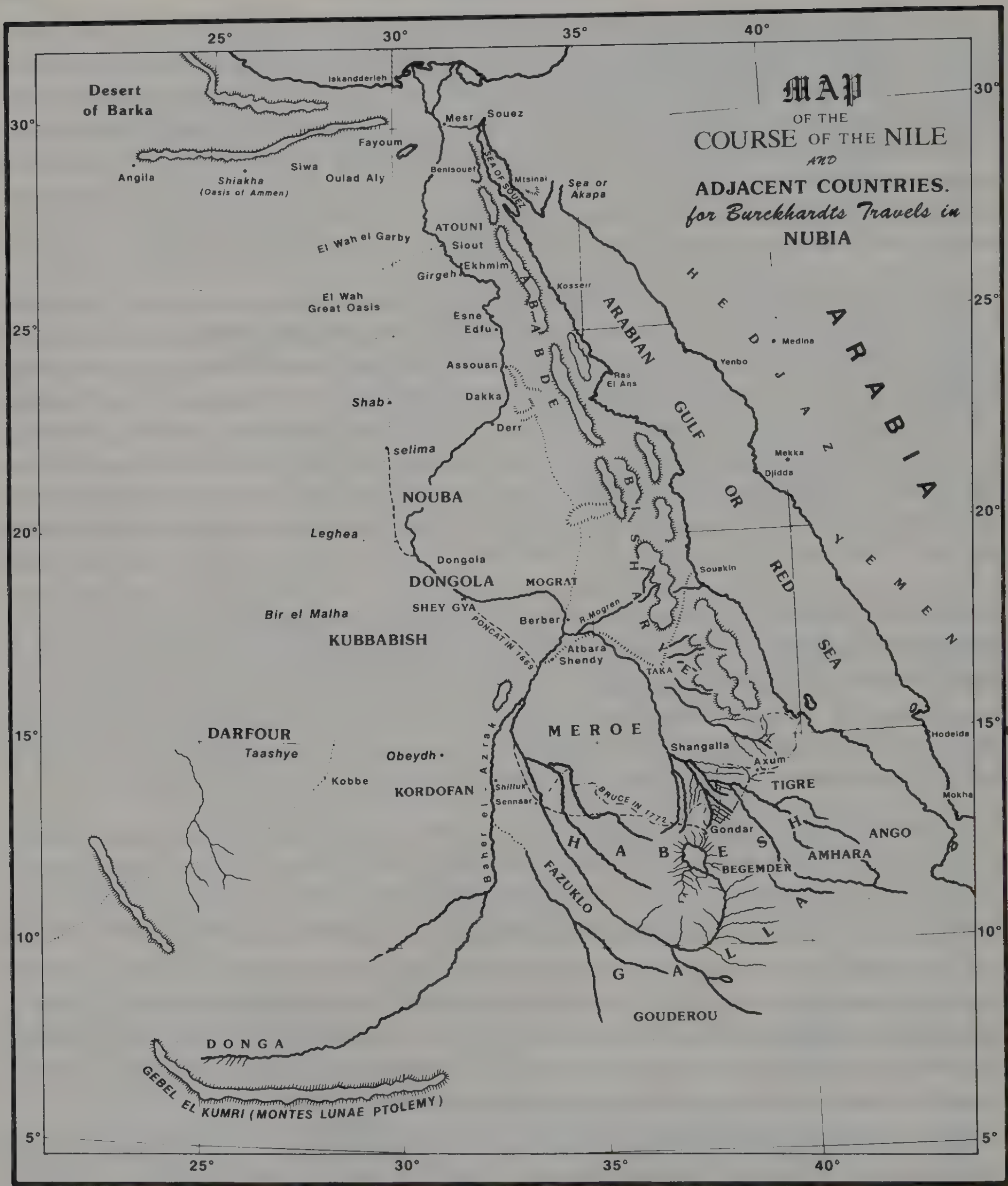

Fig. 2.4. Map of the Nile accompanying Burckhardts' book "*Travels in Nubia*" 1813 (redrawn).

the Ripon Falls and the Victoria Nile which they surmised to be the source of the Nile. They tried to paddle down this river but they were stopped by hostile natives and were compelled to proceed inland to the north until they reached Gondokoro in 1863 where Samuel Baker had camped. In the same year Speke published a paper in which he reiterated that he had discovered the sources of the Nile. This paper was received with skepticism by many and especially by Burton who believed that Speke had no basis to claim that the lake he had visited is the source of the Nile;

Speke had not traveled around the lake nor had he navigated the river which emanated from it. In view of this controversy the British Association for the Advancement of Science decided to hold a meeting in 1864 to hear Burton and Speke air their views on this subject. Speke never showed up, he committed suicide and was found dead from a gun shot. The story of the discovery of the sources of the Nile is admirably related by Moorehead (1960).

In the meantime Samuel Baker, who was camping in Gondokoro, pushed his way along the Nile until he reached Lake Albert in 1864. He was thus the first European to see the Lake. Baker then channeled the exit of the lake until the Kabarega (Murchison) Falls. Baker became an Egyptian Government functionary and was appointed Governor of the newly acquired lands of the Sudan in 1870. He annexed to Egypt large parts of country surrounding Gondokoro, Lake Albert and Uganda. Of all the officials in Egypt's employ none wrote more engagingly on exploration and hunting, of which he was extremely fond.

In the 1870's the interest of Egypt in the exploration of the sources of the Nile reached its climax. It employed many experts of different nationalities, established settlements along the newly opened areas and cleared up a 50-meter wide passage through the Sudd. The remarkable feat of opening the Sudd for navigation by large vessels was carried out by Ismail Ayub Pasha. The results of the work of Egypt in the exploration of the river can be seen in the extremely reliable map of Africa prepared by the Egyptian General Staff in 1877 and published by the Geographical Society of Egypt in 1928.

Under the direction of General Gordon, who was appointed in 1874 as governor of the Equatorial Province to succeed Samuel Baker, the exploration of the Nile was given a great impetus. In 1874–75 two English engineers, C.M. Watson and H. Chippendall, followed the river between Gondokoro and Lake Albert. In 1876 Romolo Gessi Pasha the Italian, who later was employed as the governor of Bahr el-Ghazal Province, circum-navigated Lake Albert and gave an accurate estimate of its size, which had been vastly exaggerated by Samuel Baker. In 1874 Chaille-Long, the American of the Union Army who was in the employ of Egypt, was the first to follow the river from its exit at Lake Victoria to Lake Kioga (which he named Lake Ibrahim) and hence to Lake Albert, thus establishing for the first time the connection between the two lakes.

4

THE AMOUNT OF WATER CARRIED BY THE NILE

The systematic study of the hydrology of the river started immediately after the discovery of the sources of the Nile and the opening up of the equatorial lands for settlement. Observation points were established along the entire course of the river as well as along its tributaries where the flow of the river was monitored and recorded. Today there are about 300 stations in Egypt, the Sudan and Uganda which gauge the river every day. A large number of these stations was built in the first years of the twentieth century and some were built in Nubia as late as the years following the building of the Aswan High Dam. Each station has a calibrated marble column fixed to the bank of the river (Fig. 2.5). The daily readings of these gauges are sent to the concerned departments of the governments of the different countries in which the gauges lie. In Egypt these and the readings from hundreds of other subsidiary stations along the canals go to the Nile Control Department of the Ministry of Irrigation where they are kept and studied. The ten-day and monthly averages of selected key stations are then published in supplements to the compendium "*The Nile Basin*" which has been issued by Egypt's Ministry of Irrigation since the early part of the twentieth century.

In addition to the gauge readings, the river is also monitored for the volume of water it carries, or its discharge. Since the construction of the great irrigation works of the twentieth century the discharge record has become of considerable importance in controlling and regulating the river. Prior to this the height of the water of the river during flood time was of greater importance and was watched daily until it reached the level at which the embankments of the river were cut, the fields inundated and the beginning of the agricultural season announced. The discharge is expressed in cubic meters per second (one cubic meter weighs approximately one ton) and is calculated by multiplying the average velocity measured at numerous points along the cross section of the river by the area of that cross section (Fig. 2.5). The velocity is measured by a simple instrument, the chronometer, which spins in revolutions which are directly proportional to the velocity of the river. Ordinarily the discharges are not measured every day, for they can also be deduced from the gauge readings which have a direct relationship to the volume. The gauge-discharge curves are often used to forecast the discharges of the river. Direct measurement of the discharge of the river has been in effect at Aswan since 1903. Here the discharge is measured by observing the time needed to fill basins, built in front of the Aswan Dam, with the water pouring out of its sluices. By this method it is possible to measure with great accuracy the volume of water that passes through the sluices per unit of time.

In recent years our knowledge of the meteorology and hydrology of the Lake Plateau region has been greatly enhanced by the work of the Hydromet Project instigated in the wake of the

Fig. 2.5. Upper, graduated river gauge; Lower, method of measuring discharge (after Hassan el-Sherbiny's Arabic translation of Hurst's book *"The Nile"*, Ministry of Public Works, Cairo, 1951).

sudden and great rise of the lake levels of that region in 1962 which caused the flooding of large areas. This project was designed to collect hydrometeorological data and to investigate the hydraulics of the Upper Nile Basin in an attempt to understand the causes of that rise. In 1967 five governments (Egypt, Sudan, Uganda, Kenya and Tanzania) and two United Nations Agencies (the United Nations Development Program (UNDP) and the World Meteorological Organisation (WMO)) finalized an agreement to carry out a detailed hydrometeorological survey of the catchments of Lakes Victoria, Kioga and Albert. As the work in the upper basin progressed, the governments of Rwanda and Burundi joined the project in 1972 making possible the study of the Kagera Basin and other catchment areas of Lake Victoria which lie within their boundaries. In 1971 Ethiopia joined the project as an observer. In the first phase of the agreement (1967–1972) numerous new observation points were established in order to monitor and gather time series data on some 36 individual catchment areas. Shortly after the termination of phase I Zaire joined the agreement in 1974 and asked that the study be extended to the Semliki River. Based on the large amount of hydrometeorological data compiled during phase I, the second phase, which lasted until 1981, attempted to construct a mathematical model of the rivers and lakes of the Upper Nile Basin in order to meet water resources planning requirements. The results of the work of the Hydromet Project were published in the form of several reports and papers. For a summary of the results see Hydromet report (1982).

The Nile receives its water from two major sources: the Equatorial Lake Plateau with its year round rains and the Ethiopian Highlands with its summer rains. The following table gives the average monthly discharges of some key stations along the entire stretch of the main Nile and its major tributaries for the period 1912–1982. These figures should be taken as representing the long range average of the river discharges which varied greatly during the 70 year period. The discharges of the rivers of the Equatorial Lake Plateau increased substantially after the surge of the lake levels in the 1960's while the discharges of the tributaries originating from the Ethiopian Highlands declined during the 1970's.

The following table gives the average monthly discharges at key points along the Nile for the period 1912–1982. It shows that the water which exits from Lake Victoria, at an average of 27.2 billion cubic meters per year, reaches Lake Albert with little gain; whatever flows in is almost lost in the marshes of the flat Lake Kioga. After tapping the sources of the Lake Albert Basin, the water leaves the lake at an average of 31.4 billion cubic meters. From there and up to Mongalla it picks up additional water and increases to 33.2 billion cubic meters. It then enters the Sudd region where it loses half its volume through evaporation and transpiration. Immediately after its exit from the Sudd region the supply is boosted by the Sobat River's discharge of 13.5 billion cubic meters to 29.6 billion cubic meters as measured at Malakal. That water reaches Khartoum after losing 3.9 billion cubic meters (half of which is lost in the Gebel Aulia Reservoir); there it picks up the 50.1 billion cubic meters of the Blue Nile swelling the volume of the river to 75.8 billion cubic meters. Further upstream the river picks up the discharge of the Atbara tributary which averages 10.6 billion cubic meters. It then travels across the barren Nubian country where it loses 2.2 billion cubic meters of water to reach Aswan with an average discharge of 84.2 billion cubic meters. The travel time of the water from Malakal to Aswan is 24 days in September and 39 days in May, and from Khartoum to Aswan 9 days in September and 21 days in May.

Average monthly Nile Discharges at Key Stations 1912–1982 in 10^3 cubic meters

Station	J	F	M	A	M	J	J	A	S	O	N	D	Total
Natural river Aswan	3669	2610	2261	2018	1964	1896	4362	17,696	20,880	14,391	7590	4830	84,167
K3 Atbara Mouth Atbara	—	—	—	—	—	—	1524	5004	3102	739	153	53	10,574
Khartoum mouth Blue Nile	714	448	407	399	503	1119	5497	15,972	13,976	7468	2426	1218	50,147
Malakal	2469	1754	1672	1519	1683	2047	2534	2895	3108	3442	3339	3184	29,646
Hillet Doleib Mouth Sobat	977	455	307	262	433	857	1290	1590	1760	1970	1940	1700	13,541
Mongalla	2506	2163	2312	2345	2762	2661	2906	3321	3270	3265	2939	2784	33,234
Panyango Exit Albert	2880	2476	2650	2468	2532	2467	2588	2578	2508	2711	2708	2835	31,401
Paraa Exit Kioga	1475	1295	1370	1361	2507	2521	2631	2692	2659	2747	2589	2558	26,435
Jinga Exit Victoria	2309	2055	2257	2268	2451	2394	2347	2315	2177	2209	2113	2267	27,182

The following paragraphs discuss the amount of water passing through the river at some key stations from its sources until it reaches Aswan. The location of these stations is shown in Fig. 2.6.

4.1. Jinja (Exit of Lake Victoria)

The Equatorial Lake Plateau (Fig. 1.7) begins in Lake Victoria, an enormous body of fresh water second in size only to Lake Superior and having a surface area of 67,620 square kilometers. Nearly a third of Lake Victoria's water comes from the 60,000 square kilometer Kagera River catchment area to the southwest, which gets its water from the rains falling over the Mufumbiro volcanic range of the Rwanda–Burundi Highlands. The remaining two thirds of the water of the lake come from a variety of areas: the forested slopes of the escarpments of the northeast, the drier plains of the Serengeti Plain to the southeast and the swamps of Uganda to the northwest. These areas measure about 130,000 square kilometers and extend in the territories of Uganda, Kenya and Tanzania. The annual discharge of the Kagera River measured at the Kyaka Ferry just before its entry into the lake increased from an average of 5.5 billion cubic meters per year during the 1957–1961 period to an average of 8.8 billion cubic meters per year during the period 1962–1971.

The inflow from all tributaries entering the lake is estimated to be about 18.5 billion cubic meters per year while that from direct rainfall is about 113 billion cubic meters. These figures are from the publications of the Hydromet staff (Krishnamurthy & Ibrahim 1973) and they are almost double the figures given by Hurst (1957). While close to 75 percent of this water is lost to evaporation, the rest flows out of the lake via the Victoria Nile to the north. The discharge of this river, as measured at Jinja station at the exit of the lake, surged from an average of 23 billion cubic meters per year during the period 1896–1961 to an average of 41.4 billion cubic meters per year during the period 1962–1965 and to an average of 33.3 billion cubic meters for the period 1962–1982. The surge in the discharge of the river occurred suddenly in 1961 and caused a rise in Lake Victoria's level of 2.2 meters during the period 1961–1964 (Fig. 2.7) causing the flooding of the low-lying areas around the lake. The flooding was especially felt in the Kavirondo Gulf and the port of Kisumu in Kenya.

The sharp rise in the level of Lake Victoria between 1961 and 1964 is difficult to explain in terms of the components of the water balance of the lake, and some authors believe that the rise may have been due to intense earthquake activity that affected the groundwater regime changing the aquifer elasticity and causing sudden water surface fluctuations (Salem, Imam & El Bab 1979). Other authors attribute the rise to the manipulation of the Owen Falls Dam levels by the Egyptian engineers who run the dam, a claim which was propagated by some workers (Okidi 1991) and refuted by the Hydromet project which found that the "dam was the cause of only 0.03 meters of the total rise in lake level, over the period 1957 to 1980" (Hydromet 1982, annex 7, page 39). Most authors believe that the rise of the lake level was due to an increase in rainfall in the Lake Plateau. According to the Hydromet report, an increase in precipitation of 25–30 percent above the long-term mean was needed to bring about the observed rise in the lake levels. Such an increase was not observed, perhaps because the data of over-lake precipitation and evaporation were incomplete (Hydromet 1982). Recently a review of the inflow data and the method of calculating rainfall from lakeside gauges has demonstrated that a sequence of three years with rainfall above the average, together with the tributary flows

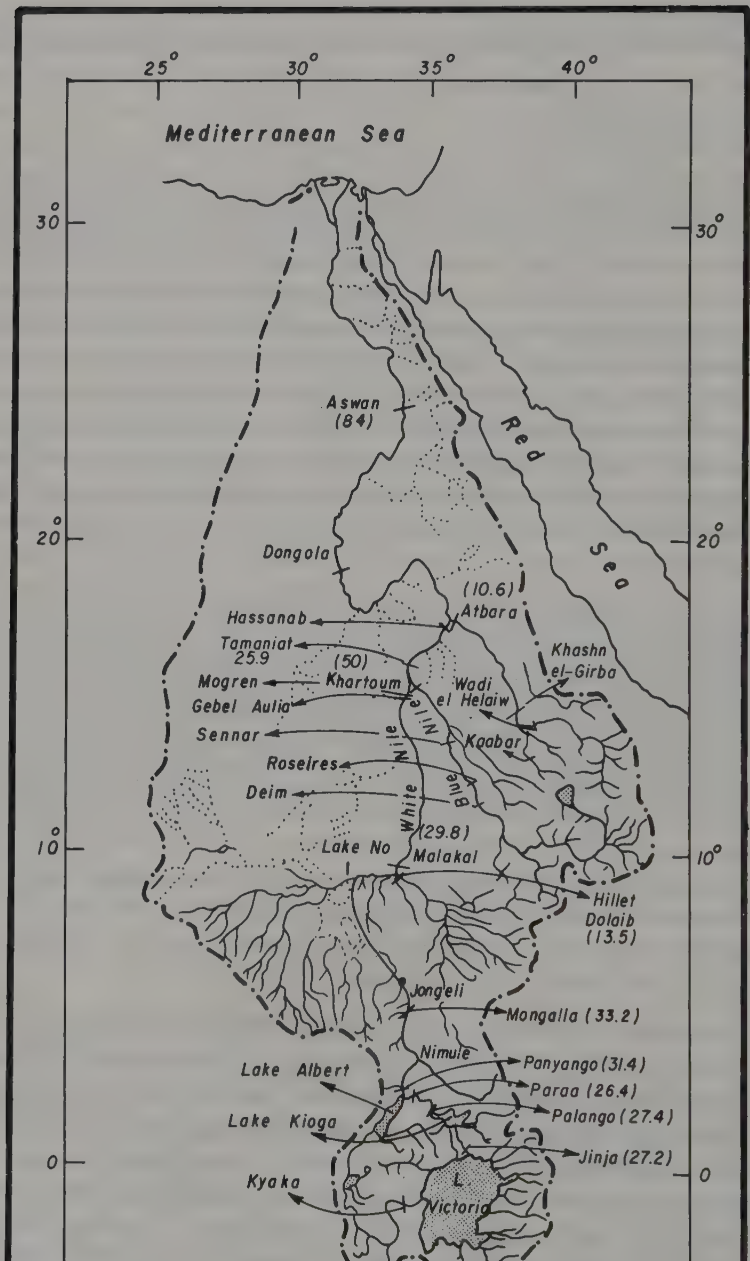

Fig. 2.6. Main monitoring stations on the Nile, with the 1912–1982 average discharge in billion cubic meters of the river given in brackets.

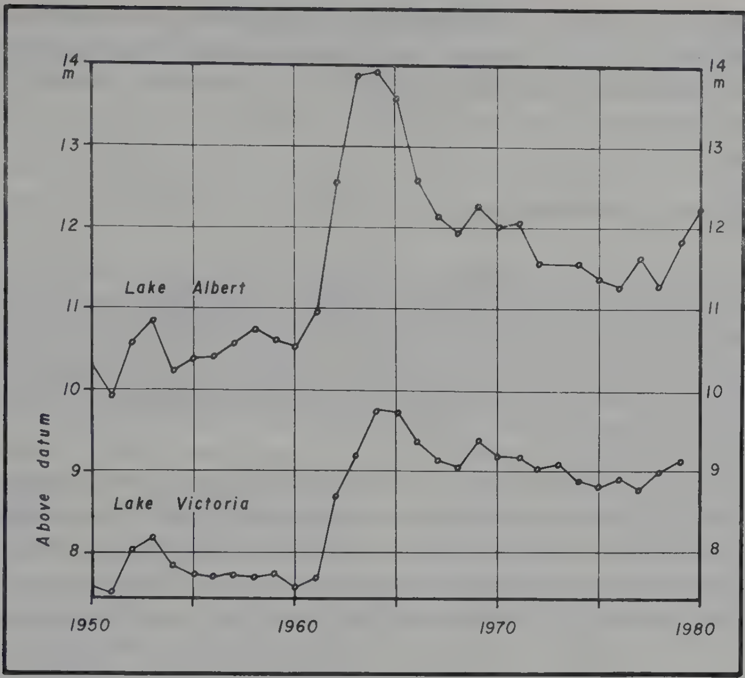

Fig. 2.7. Beginning of year average levels of lakes Victoria and Albert above datum (datum of Lake Victoria is 1022.15 above sea level and of Lake Albert is 609.82 meters above sea level).

responding to this rainfall but amplifying its variation from the mean, is sufficient to explain the surge of the lake level which occurred in the early 1960's (Piper, Plinston & Sutcliffe 1986). The precipitation over the lake increased from an average of 1611 millimeters per year in pre-1961 years (1950–1961) to an average of 1938 millimeters per year in the three years 1962–1964. After 1965 the rainfall has fluctuated from a minimum of 1355 millimeters per year in 1980 to a maximum of 2086 millimeters per year in 1977.

4.2. Paraa (Exit of Lake Kioga)

The Victoria Nile passes through the many-armed Lake Kioga from where it descends rapidly to Lake Albert via the Kabarega (Murchison) Falls. In pre-1962 years Lake Kioga received, over and above the 23 billion cubic meters of water from the Victoria Nile, an average of 3 billion cubic meters of water from inflow from land runoff and rainfall. In the meantime it lost by evapotranspiration close to 4 billion cubic meters per year, resulting in a net loss of one billion cubic meters per year; the average discharge at the exit of the lake during the same period was about 22 billion cubic meters. Pre-1962 discharge figures from the Lake Plateau are scattered through the literature and the figures given here are for the years 1912–1944 and are from Hurst, Black & Simaika (1946). The figures given by the Hydromet Project for Lake Kioga for post-1961 years show that land runoff and rainfall compensated evapotranspiration and increased the outflow from the lake to an average of 42.9 billion cubic meters per year for the period 1962–1965. During these years Lake Kioga levels rose sharply. The amount of runoff to

the lake is given as 2.9 billion cubic meters per year, the amount of rainfall over the basin as 5.5 billion cubic meters and the amount of evapotranspiration as 6.9 billion cubic meters. The net contribution of the lake's basin to the waters of the Nile, therefore, is about 1.5 billion cubic meters per year. The average flow from the lake for the period 1962–1982 is 34.7 billion cubic meters per year.

4.3. Panyango (Exit of Lake Albert)

Lake Albert, into which the waters of Lake Kioga flow, also receives the waters of the hydrologic unit of Lakes Edward and George (which are today interconnected) via the Semliki River. The average discharge of this unit at the mouth of the Semliki has also increased since 1961. It averaged 3.8 billion cubic meters per year for the five-year period 1956–1960 (the discharge for the year 1961 is not available) and 5.9 billion cubic meters of water per year for the nine-year period 1962–1970.

The discharge of Lake Albert itself, measured at Pakwatch and Panyango, increased dramatically from 18.7 billion cubic meters of water per year for the five year period 1957–1961 to 45.7 billion cubic meters of water per year for the four-year period 1962–1965. During these latter years the lake level rose suddenly from about 11 meters in 1961 to about 13.9 meters in 1962 and reached a peak of 14.2 meters in 1963 (Fig. 2.7). From 1904, the year systematic measurements of the discharge started to be taken at its exit at Pakwatch (upstream from Panyango), until 1944 the lake had an average discharge of only 24.7 billion cubic meters of water per year. The figures given by the Hydromet Project for Lake Albert show a dramatic increase in the discharge of the lake, increasing to an average of 37.6 billion cubic meters per year for the period 1962–1982. River discharge into the lake and runoff from its basin amount to 7.3 billion cubic meters a year, while the rainfall on the lake is in the range of 3.8 billion cubic meters, and the amount of evaporation is 8.2 billion cubic meters. The net contribution of the lake to the waters of the Nile is, therefore, in the range of 2.8 billion cubic meters per year.

4.4. Mongalla (Entrance of the Sudd, Upstream Bahr el-Gebel)

From its exit at Lake Albert down to Mongalla, where the river enters the great Sudd swamps, a number of streams join the Nile (known in this stretch as the Bahr el-Gebel) and swell the river during the rainy season. At Nimule on the Uganda–Sudan border it receives the flow of the Aswa River. The discharge of this river averaged 1.6 billion cubic meters per year for the period 1923–1965 when measurements were taken regularly. Other small but torrential streams join the Nile in this stretch and swell the river after the rains. Of these streams the Kaia and the Kit are the largest. These and other streams feeding the river downstream from Nimule contribute an amount of about 1.2 billion cubic meters per year. Other streams which join the river upstream of Nimule contribute another 1.5 billion cubic meters per year. Hydrological data of this stretch of the Nile are scanty and the figures given here for the streams must be taken as approximate (Shahin 1985).

The total amount of water contributed by torrents to the entire stretch is 4.3 billion cu meters per year, boosting the discharge of the river at Mongalla to 45.7 billion cubic meters for the 1962–1982 period. There was a surge in the discharge of the river at Mongalla after 1961; it increased from an average of 26.5 billion cubic meters for the five-year period 1957–1961 to

an average of 51.9 billion cubic meters for the 1962–1965 period. The average for the entire period (1912–1982) was 33.2 billion cubic meters per year.

4.5. Malakal

Discharges at this station represent the net quantity of water coming from the equatorial lakes (after passing through the Sudd), as well as that coming from the Bahr el-Ghazal and the Sobat River.

For a distance of 700 kilometers extending from Mongalla to Lake No the river passes through an open and flat plain where it overflows its banks and becomes no longer confined to one channel (Fig. 1.8). Extensive swamps spread out on both sides of the river in this stretch. Dry land can hardly be seen and the river flows between walls of papyrus and tall grass reaching 4 to 5 meters in height with their roots in water. North of Bor, along the east side of the river, some of the water patches are drained back into the river by well-defined rivers the most important of which are the Atem, along whose banks lies the town of Jonglei, the Awai and the Bahr el-Zaraf. Bahr el-Zaraf starts to the west of the swamps of the River Awai and follows a winding course of about 280 kilometers to its mouth on the White Nile some 80 kilometers east of Lake No. At Lake No the Bahr el-Gebel is joined by the Bahr el-Ghazal and the combined stream turns abruptly to the east where it is called the White Nile. Here the swamps end and after a short distance the river flows northward.

The contribution from the Bahr el-Ghazal basin, which constitutes more than 20 percent the total basin area of the Nile (Fig. 1.8), is minimal. The Bahr el-Ghazal River, which extends for 160 kilometers from Meshra el-Req to Lake No, receives the drainage of this impressive basin whose annual rainfall provides it with an estimated 400 billion cubic meters of water. Of these, only 600 million cubic meters, or slightly more than one thousandth of the total amount of water received by the basin, reach the basin's outlet at Lake No every year. All along the basin there are large areas of swamps which are fed by a number of poorly-defined streams. Many of these streams start at the Nile–Congo divide. They are from west to east: Bahr el-Arab, Lol, Jur, Ibba or Tonj, Gel or Meridi, Naam and Yei or Lau.

The Jur is the only river which preserves its channel until it joins Bahr el-Ghazal. It has the maximum discharge of all the rivers of the basin (190 million cubic meters per year measured at Wau). It is followed by the River Lol (157 million cubic meters per year) and the River Yei (126 million cubic meters per year). These figures are averages for the years prior to the year 1936 when measurements of the discharges of these rivers became erratic and are all from Hurst & Phillips (1938). Regular measurements, however, were resumed at Wau between 1942 and 1972; the average discharge was found to have increased during that period to 500 million cubic meters per year. It also increased at Nyambell on the River Lol to 400 million cubic meters per year for the period 1944–1974 and to 200 million cubic meters per year at the Mundri Bridge on the River Yei for the period 1944–1960. It can, therefore, be said that the amount of water reaching the Bahr el-Ghazal tributaries doubled during the mid years of the twentieth century when compared with the early years of that century.

The River Sobat, which joins the White Nile just before Malakal, is formed by the confluence of the Rivers Baro and Pibor (Fig. 1.12). The Baro comes from the Ethiopian Highland and flows from east to west, while the Pibor flows from south to north. The principal tributaries of the Pibor

also rise in the Ethiopian Highland though the most southern ones rise in the Uganda Plateau. The Ethiopian tributaries and the Baro are torrential streams contributing considerable quantities of water in flood time; their discharges are reduced to a trickle, or in some cases to no discharge at all, in the dry season.

All the streams forming the Sobat rise in the mountains and have well-defined channels until they enter the flat plain at the foot of the mountains where they tend to overflow their banks and form swamps. In these stretches they lose large quantities of water by evapotranspiration. In this respect they resemble the tributaries of the Bahr el-Ghazal. However, in the case of the Sobat and its tributaries the area of permanent swamp is small, though in years of heavier rainfall it becomes very large such as happened during the early 1960's when practically the whole plain from the Ethiopian mountains to the Bahr el-Gebel was under water. The Sobat differs also from Bahr el-Ghazal in that none of its tributaries disappear in swamp. The reason for this is probably the greater slope of the Sobat tributaries in the plains.

The Baro contributes about three quarters of the discharge of the Sobat even though its basin is only 41,400 square kilometers or barely 22 percent of the total area of the basin of the Sobat. The channel of the Baro in the flat plains below the Ethiopian town of Gambeila cannot carry the peak discharge of the summer months and the water is permanently lost by over-bank spills. Water is also lost in this stretch by natural diversions to Khor Adura and Khor Machar. In years of high rainfall Khor Adura returns again to join the Baro a few kilometers upstream of its junction with the Pibor after receiving the drainage of its southern tributaries. The average discharge of the Baro when it reaches the Pibor junction is 7.8 billion cubic meters of water per year. It loses from Gambeila to this junction about 3.9 billion cubic meters per year.

Much of this loss occurs in the reach between Khor Jakau and Khor Machar. The latter Khor connects the Baro to the Machar marshes which constitute an enormous area of low lands. The marshes vary in area from 6500 to 20,000 square kilometers depending on the intensity of the local rainfall, the inflows from the eastern Khors and the overbank spills from the Baro. On average, the marshes receive about 0.9 billion cubic meters of water from the Baro via Khor Machar, some 1.7 billion cubic meters of water from the eastern khors which emanate from the mountains and some 3.9 billion cubic meters of water from the overbank spills of the Baro.

The Pibor, which flows from south to north, has its principal tributaries in the Ethiopian Highland; the largest of these is the Gila River. The Pibor contributes less than one-quarter of the Sobat discharge. Its maximum discharge occurs in the months of November and December when the discharges of the Baro and the main streams of the Sobat begin to decrease. The Pibor has some of its sources in the Lake Plateau and its flow is, therefore, more even over the year. It is for this reason that the Pibor plays an important role in the hydrology of the river and the continuity of its flow.

The Sobat contributes about 61 percent of the discharge of the White Nile at Malakal during the months of October to December; but in February, after its level decreases, it provides less than one-quarter of the White Nile discharge. Because of the overbank spills the Sobat has a water carrying capacity that it cannot exceed; its discharge has been almost constant over the years, hovering around the 13.5 billion cubic meter mark. It is only in the years when there are larger than usual contributions from the Pibor and the peak discharge months extend beyond the month of October that the river has higher than average discharges. The highest discharge on record was in the years 1917 and 1918 when it was above the 20 billion cubic meter mark (Hurst

1950). During the 1960's its annual discharge increased to an average of 15 billion cubic meters as a result of overflows from the Pibor. The minimum discharges were in the years 1913, 1940, 1972 and 1982 which recorded 9.5, 9.1, 9.1 and 8.1 billion cubic meters respectively.

The Malakal discharge resulting from the waters of Bahr el-Gebel and the Sobat increased from a long-term annual average of 29.8 billion cubic meters for the period 1914–1982 to an average of 35.4 billion cubic meters per year for the period 1962–1982.

The following table shows the amount of water in billion cubic meters received at Mongalla (Sudd entrance), Lake No (Sudd exit), Hillet Doleib (Mouth of Sobat) and Malakal.

Period	Mongalla	Lake No	Hillet Doleib	Malakal
1912–1982	33.2	16.2	13.6	29.8
1957–1961	26.5	13.7	13.0	26.7
1978–1982	45.7	18.5	13.2	31.7

Out of all the water entering the Sudd at Mongalla during the period 1912–1982 only 49 percent exited from the basin; the rest was lost by evapotranspiration. The loss increased to about 60 percent during the period of high inflow from the Lake Plateau. Inspite of the enormous increase in the quantity of water reaching the Sudd from the equatorial lakes since the 1960's, the quantity of water exiting from it has barely increased. During the period of high flow an additional 19 billion cubic meters of waters entered the Sudd every year over and above the average yearly inflow. Of these only one quarter (4.8 billion cubic meters) exited from the Sudd. This underscores the fact that the Sudd acts as a barrier that limits the amount of water that the Lake Plateau sources can contribute to the Nile. The size of the Sudd swamps increased manyfold after the 1961 surge of rainfall. The size of the flooded areas of the Sudd was estimated upon the basis of a hydrological model that was devised by using the inflow and outflow records, the evaporation estimates and the long-term rainfall series obtained by the Jonglei Investigation team (1946–1954) and the FAO project (1982). The estimates were comparable to those obtained by the use of air photography and satellite imagery. The satellite imagery and the hydrological model both showed that the flooded areas, which averaged about 8000 square kilometers before 1961, increased to about 30,000 square kilometers in 1964 following the rise in the level of Lake Victoria; since then they have remained between 20,000 and 30,000 square kilometers (Sutcliffe & Parks 1987).

4.6. Mogren

The discharge readings at Mogren represent the Malakal discharges minus the natural losses of the river during its journey of 800 kilometers along the White Nile, the Gebel Aulia reservoir losses and the abstractions of the pump stations along that stretch. To obtain the natural flow of the river these must be added to the readings of this station. The White Nile between Malakal and Gebel Aulia receives no tributary of importance. It is a wide, placid stream with a very gentle slope often having a narrow fringe of swamps. The valley is wide and shallow thus causing a considerable loss of water by evaporation from its relatively large surface area. Gebel Aulia reservoir was built in 1937, a few kilometers to the south of Khartoum, to provide water for

Egypt during the season of low water. The reservoir is still in operation though the regulation it affords ceased to be significant to Egypt after the construction of the Aswan High Dam. Although the height of the Gebel Aulia Dam is limited, it is enough to create a backwater effect for some 600 kilometers up to Melut because of the very small slope of the White Nile. Prior to the construction of the dam the Blue Nile flood wave formed a natural barrier to the White Nile giving a backwater effect similar to that of the Gebel Aulia Dam.

Discharge data (Fig. 2.8) show that the flow at Mogren soared from an average of 25.6 billion cubic meters per year for the period 1912–1961 to an average of 33.9 billion cubic meters per year for the period 1962–1985. The long term mean is 28.3 billion cubic meters. An average of about 3.9 billion cubic meters per year is lost along the Malakal–Mogren stretch. Of these losses

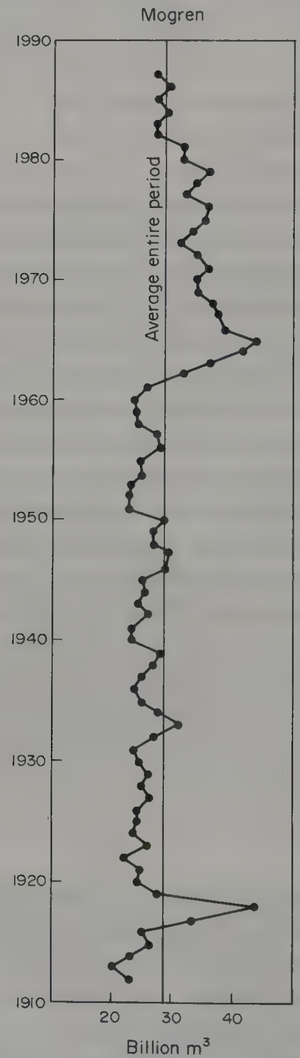

Fig. 2.8. Average yearly discharge at Mogren 1912–1987. The average yearly discharge for the entire period is 28.3 billion cubic meters and for the 1962–1987 period is 33.9 billion cubic meters.

it is estimated that between 2 to 2.5 billion cubic meters of water are lost due to evaporation from Gebel Aulia reservoir and the remainder to natural losses. Natural losses along this stretch vary from year to year; they become exceptionally high when the flow at Malakal exceeds 36 billion cubic meters per year causing the water to overflow the banks of the shallow river.

4.7. Khartoum

The discharges of the Blue Nile are measured at four main stations, the Deim on the Ethiopian–Sudan border established in 1962, the downstream Roseires and Sennar Reservoirs and Khartoum. The natural discharge of the Blue Nile is calculated by adding to the readings of the Khartoum station the losses incurred at the Roseires and Sennar dams and the abstractions along the river (including the outflows to the Gezira and Managil Canals necessary for the irrigation of the lands of the Gezira Project at the confluence of the Blue and White Niles). The natural discharge at Khartoum includes that of the Blue Nile and its tributaries the most significant of which in the Sudan are the Dinder and Rahad. These rivers contribute respectively an average of 2.9 and 1.1 billion cubic meters per year to the discharge of the river.

The Blue Nile is an important tributary of the Nile; it contributes a large part of its water. The hydrology of the river is governed by the severe tropical rains which produce its summer flood; hence the importance of rainfall data for the Ethiopian Highland which are, most unfortunately, lacking for recent years. The discharge of the Blue Nile has not been constant over the years of this century (Fig. 2.9). Its long term average was 51.7 billion cubic meters per year for the period 1912–1986. However, the average for the early years of this series (1912–1964) was 52.7 billion cubic meters per year and for the period 1965–1986 was 45.6 billion cubic meters per year. The 1978–1986 years were among the lowest with an average of 34 billion cubic meters per year. There were only three years during this century when the Blue Nile discharge exceeded 70 billion cubic meters; these were the years 1916, 1917 and 1929. There were four years in which the discharge exceeded 60 billion cubic meters; these were the years 1935, 1938, 1954 and 1964. The lowest years of the century were the years 1913, 1972 and 1985 when the discharge measured only 23, 30 and 25 billion cubic meters respectively, less than half the long range average. Drought in the Sahel affected the river flow; it was severest in the latter years of the 1970's and throughout the 1980's. The hydrology of the Blue Nile is best described in Hurst, Black & Simaika (1959).

4.8. Atbara K3

The discharge of the Atbara River is measured at the Kaabar and the Wadi el-Helaiw stations situated at the Atbara and its tributary, the Setit, as they enter the Sudan. These two stations were built in 1962 before the operation of the Khashm el-Girba reservoir. The natural discharge of the Atbara at its mouth before it enters the Main Nile is calculated by adding the readings of this station to the losses from the Khashm el-Girba reservoir and the abstractions of the feeder canals of the new Halfa agricultural project designed to help relocate the Sudanese Nubians after the building of the Aswan High Dam.

The long range average of the discharge of the Atbara River at its mouth was 10.6 billion cubic meters per year for the period 1912–1982. The highest discharge was in the year 1916 (27 billion cubic meters) followed by the years 1922, 1954 and 1959 with discharges of 17.5,

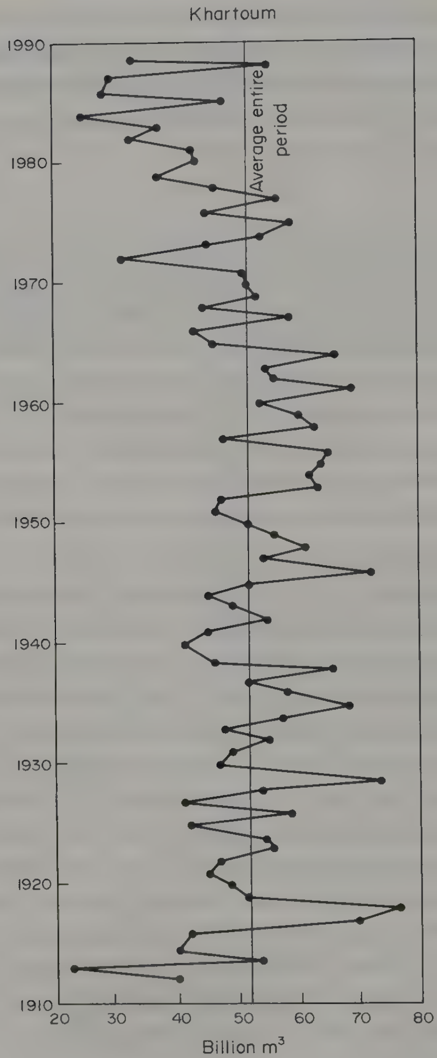

Fig. 2.9. Average yearly discharge at Khartoum 1965–1986. The average yearly discharge for the entire period is 51,7 billion cubic meters and for the 1978–1982 period is 34.2 billion cubic meters.

21.1 and 17.1 billion cubic meters respectively. The lowest discharges were in the years of drought in the Sahel 1939–1941, 1965–1972 and 1978–present. The average annual discharge for the years 1914–1938 was 11.5 billion cubic meters per year and 9.5 billion cubic meters for the years 1966–1982. The 1978–1982 average reached the minimum of 6.2 billion cubic meters. Of the eight-year period 1965–1972, two years, 1967 and 1970, were higher than average (14.2 and 12.7 billion cubic meters respectively), and six years averaged seven billion cubic meters each.

5

THE NILE AT ASWAN

After leaving Atbara, the last of its tributaries before it enters the Sahara, the Nile is monitored at the main stations at Dongola and then at Aswan. The reconstruction of the natural flow of the river at Aswan is made by adding the discharge of the river at that station to the upstream abstractions which have increased after the building of the great irrigation structures of the twentieth century and the expansion of Sudan's agriculture. Until 1971, when the Aswan High Dam became fully operational, the upstream abstractions and losses did not exceed 4 to 5 billion cubic meters of water per year. As the High Dam started to fill, evaporation losses from the surface of the reservoir (Lake Nasser) and the use of water by the Sudan became large and sizeable. Evaporation losses from the Aswan High Dam reservoir since 1971 have hovered around the 10 billion cubic meter mark per year and have ranged form 7.6 to 13.2 billion cubic meters; years of higher flow cause the reservoir to have a larger surface area and higher rates of evaporation. The Sudan has also increased its use of the water of the Nile. Its withdrawals have increased steadily since the beginning of the operation of the Aswan High Dam in the late 1960's from about ten billion cubic meters to about 14 billion cubic meters in 1986.

The contribution of the different tributaries to the natural discharge at Aswan between the years 1912 and 1982 averaged 30 percent from the White Nile (of which 45 percent came from the Sobat), 58 percent from the Blue Nile and 12 percent from the Atbara. During years of high discharge most of the additional waters came from the Blue Nile and the Atbara. In the exceptionally high years of 1916 and 1946 these two rivers contributed 79 and 76 percent of the discharge of these years respectively.

The significant increase in the Lake Plateau waters of the 1960's did not have a great impact on the discharges at Aswan as one might have surmised. The largest part of that water was lost in the Sudd; only an average of 8 billion cubic meters per year was able to escape to the Main Nile in post-1962 years. This loss was not only due to the filtering effect of the Sudd region, which we have already alluded to, but also to the limited carrying capacity of the White Nile, the main conduit of the waters of the Lake Plateau to the Main Nile. There was an average increase of 30 percent in the contribution of the White Nile in the 1960's which, when added to the slightly higher flows of the Ethiopian tributaries during this period, raised the discharges at Aswan for most of the years of the 1960's. The surge of rainfall in the Equatorial Lake Plateau during the early years of the 1960's was not accompanied by a similar surge in the rainfall of the Ethiopian Highlands. After a short spell of slightly higher rainfall in the early 1960's the Ethiopian Highlands witnessed a decline in the rainfall starting from 1967, a decline which became especially noticeable during the 1970's and 1980's. During these two decades the

additional waters that came from the Lake Plateau barely compensated for the decline in the contributions of the tributaries of the Ethiopian Highlands.

Figure 2.10 plots the natural discharge of the river at Aswan from the year 1870, the year systematic measurements started, to 1988. A glance at that figure shows that the discharges of the last years of the nineteenth century were considerably higher than those of the twentieth century. The average discharge of the period 1870–1899 was 110 billion cubic meters per year. The highest discharge during this period was that of the year 1878 when it reached a record high of 141.6 billion cubic meters. The lowest was that of 1877 when it reached 77.4 billion cubic meters.

The average discharge of the 90-year period of the twentieth century, on the other hand, declined to 84 billion cubic meters per year. There were only 13 years in this 90-year period which had a discharge above the 100 billion cubic meter mark compared to 21 years out of the last 30 years of the nineteenth century. The change in the amount of water carried by the river at the turn of the twentieth century was sudden and clear-cut; it showed in the gauge levels and in the average discharge of the low months as well as the flood months. The average flood gauge levels in Aswan and Cairo decreased from 8.2 and 6.5 meters in Aswan and Cairo respectively in the period 1870–1899 to 7.8 and 4.8 meters in the period 1899–1932. The average discharge during the low months of February to June decreased from 13.2 billion cubic meters for the 1870–1899 period to 10.7 billion cubic meters for the 1900–1988 period. The average discharge of the flood months (August to October) also decreased from 66.1 billion cubic meters for the 1870–1899 period to 50.1 billion cubic meters for the 1900–1988 period.

It has been claimed that the difference between these two periods was due partly to the way the discharges were measured before and after the construction of the Aswan Dam in 1902. In the pre-1902 period the measurements were based on a gauge at Aswan calibrated by infrequent float measurements. In the years following the building of the dam the discharge measurements were direct and were conducted in large downstream tanks as already mentioned. By carefully comparing the Aswan and Wadi Halfa flows before and after 1902, it became evident that the pre-1902 flows had been overestimated by about 8 percent (Hurst & Phillips 1933). However, when this percentage was subtracted, the pre-1902 discharges were still substantially higher than the post-1902 flows.

An examination of the twentieth century discharge records at Aswan shows that this has been, on the whole, a century of lower flows interrupted by years when higher flows or exceptionally lower flows persisted. Years with higher than the long-range average of the century are concentrated in the periods 1946–1967 and 1974–1978. Years of exceptionally low flows are concentrated in the periods 1968–1973 and 1979–1987 (and still persisting at the writing of this manuscript in 1992). The flows of the early years of this century at Aswan were the closest to what one would call "normal". From 1900 to 1945 the river flow hovered around the average of the century for about 40 percent of the time. It was this average that irrigation engineers had to contend with and to consider when planning the agricultural expansion in Egypt during the early years of this century. This average was also the basis for the apportioning of the waters of the Nile between the Sudan and Egypt as stipulated in the 1959 Water Agreement. During this period there were years in which the river was high; five years had discharges that exceeded the 100 billion mark. The highest discharges were 109.8 and 110.2 billion cubic meters for the two successive years of 1916 and 1917. There were also eleven years with discharges below the

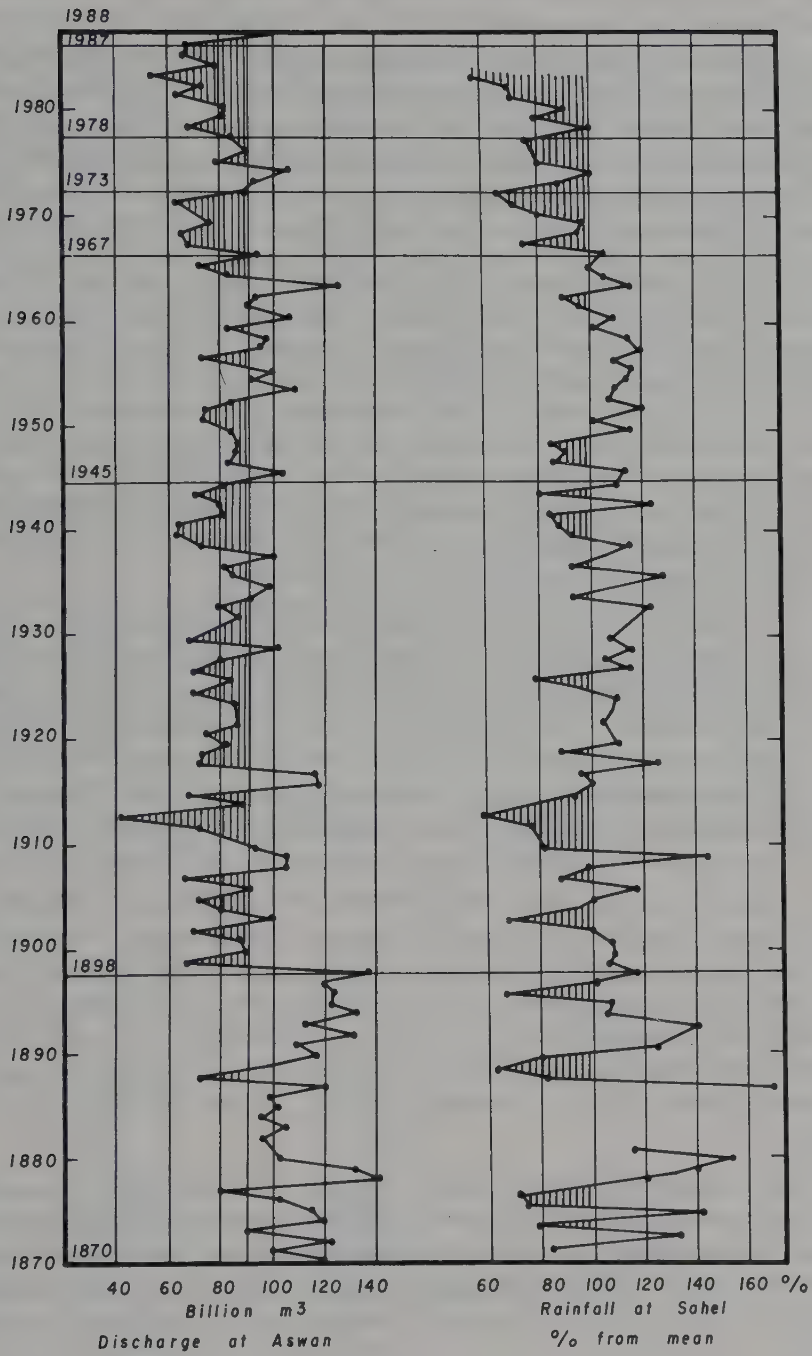

Fig. 2.10. Average yearly discharge at Aswan and the rainfall of the Sahel (plotted as percentages from the mean).

75 billion mark. The lowest ever recorded for this period or any other was 45.9 billion cubic meters in 1913.

The discharges of the years 1945–1967 increased to an average of 90 billion cubic meters per year. The early years of the 1960's, in particular, were unique years in the twentieth century. Their increased rains were reminiscent of those of the latter years of the nineteenth century and were taken as marking a return to the earlier climatic pattern of those years which had prevailed until the onset of the warming trend at the beginning of the twentieth century and which had caused "a reversal of the change of behaviour of the large scale wind circulation" (Lamb 1966).[1]

During the 1960's the African lake levels significantly rose, as we have noted, and the Sahelian belt enjoyed a period of wet climate. Many African states which gained their independence in the 1960's embarked on plans to develop their natural resources on the assumption that this climatic pattern would continue. However, after 1967 the pattern was reversed bringing a dramatic decline in rainfall and disrupting the development plans of these nations: reservoirs which were built to receive the expected high flow of the rivers were not filled, electricity was not generated and reclaimed land was left fallow. The impact of this drought on the economy and welfare of the people of the semi-arid zone of the Sudan where there was a major decline in aquifer recharge and total exhaustion of shallow wells, surface pools and reservoirs, was devastating (Walsh, Hulme & Campbell 1988).

From 1967 on there was a decline in the Nile discharges which dropped to an average of 75 billion cubic meters per year for the years 1968 to 1988. Had the lower flows of this period persisted, there would have been no excess water to fill the reservoir behind the Aswan High Dam which was completed in the opening years of this period. Fortunately, there were five successive years during this period (1974–1978) in which the discharge of the Nile was high, averaging 93 billion cubic meters per year; this allowed the reservoir behind the dam to be filled to almost its full capacity in 1979. In fact the two great floods of 1974 and 1975 account for the large part of the rise of the High Dam reservoir during this period (Stoner 1990).

Figure 2.10 shows clearly that the fluctuations in the discharge of the Nile as recorded in Aswan correlate well with the Sahelian climatic events, decreasing during drought years and increasing during years of high rainfall. The Sahelian drought has been the subject of intensive studies (see for example Mason 1977 and Spittler 1985). During the drought years of 1911 – 1915, 1940 – 1944, 1968 – 1972 and 1982 – 1987 the annual Nile discharge at Aswan averaged well below the average of the century. During these periods it averaged 70 , 74 , 69 and 67 billion cubic meters respectively.

It has been suggested that the years of low Nile discharge may be connected also to the El Nino Southern Oscillation (ENSO) climatic event which affects the coasts of Peru, Ecuador and northern Chile, but which is now recognized to have world-wide effects on the climate (Glantz 1987) It does indeed determine, at least in part, the characteristics of the Tropical Easterly Jet and the location of the Intertropical Convergence Zone which, in

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[1]It is interesting to note here that the warming trend that occurred at the beginning of the twentieth century (and which was reversed in the mid years of the century) caused as much anxiety about its consequences then as is happening today among the advocates of the global warming theory.

turn, determine the moisture characteristics of the Sahelian zone (Hulme 1990). In this climatic event, which occurs from time to time, a warm surface water current from the western equatorial part of the Pacific Basin invades the eastern equatorial region. Ordinarily the sea surface temperature along the eastern coast of the Pacific is unusually cool for an equatorial region. This is caused by the currents which flow equatorward from the cool higher latitudes and also by the welling to the surface of cool subsurface water. Occasionally, warm surface water invades the eastern equatorial Pacific and disrupts the upwelling along the east coast of the Pacific. This affects the productivity of the sea and damages the fishing industry along this coast. It seems also to trigger world-wide effects. Years of strong ENSO have been observed to be associated with floods, severe storms, tidal surges, droughts and other climatic disruptions in far off places in both the Southern Hemisphere and, with lesser correlatability, the Northern Hemisphere. In general, over the continents drought occurs in the tropics and excess rainfall in the temperate latitudes.

It has been demonstrated that the El Nino years produce mean precipitation deficits of between minus 5 percent and minus 15 percent over the Nile Basin, while more significantly the anti-El Nino years (El Ninas) are associated with mean positive anomalies of between plus 10 percent and plus 25 percent and between plus 5 percent and plus 10 percent over the White and Blue Nile catchments respectively (Janowiak 1988). The relatively high precipitation of the El Nina year of 1988 over the Nile Basin (plus 8 percent and plus 13 percent over the White and Blue Nile catchments respectively) and the subsequent high Nile flood is the most recent example which fits into this pattern of ENSO forcing on Nile Basin precipitation (Hulme 1990).

The El Nino occurrences are well documented. Quinn & Neal (1987) used applicable publications to list and classify these occurrences during the past four and a half centuries. Below are listed the occurrences during the past 120 years, their strength and the Nile discharge at Aswan in that year.

El Nino	Strength	Discharge at Aswan (billion m^3)
1877/78	very strong	74
1884	strong	92
1891	very strong	103
1899/00	strong	71
1911/12	strong	70
1917	strong	110
1925/26	very strong	69
1932	strong	87
1940/41	strong	66
1957/58	strong	77
1972/73	strong	69
1982/83	very strong	72

There is a correlation between the El Nino occurrences and the years of low floods. With the exception of the years 1891, 1917 and 1932, all other years were among the lowest years with regard to flood levels. However, there are many other years with low floods that do not seem to be associated with this event. The 1913/14 exceptionally low Nile came two years after the 1911/12 El Nino event. Evidence correlating the Sahelian drought and the El Nino is conflicting (Ogallo 1987), and it would be difficult at present to predict the discharge of the Nile on the basis of the El Nino alone.

6

PAST FLUCTUATIONS OF THE NILE

"The river of Egypt is empty, men cross over the water on foot". Neferty (ca. 1990 B.C.).

In the previous chapter we discussed the fluctuations of the discharge of the Nile during the last 120 years and demonstrated that these fluctuations were best correlated with the position of the Sahelian rain front; the amount of the flood waters increased during the years of its northward advancement and decreased during the drought years resulting from its retreat. In this chapter we shall deal with the fluctuations of the floods of the Nile prior to the introduction of modern measuring instruments and the systematic recording of data. Our knowledge of these fluctuations comes either directly from the fragmentary record of measurements as registered on the nilometers which existed all over Egypt from the earliest of times or indirectly and by inference from geological evidence or from eyewitness accounts of the conditions of Egypt in different periods of time. The geological evidence is based on the study of the terraces which the river left behind as it excavated its course and of the deposits which filled its flood plain as it aggraded its bed. The height and position of the terraces establish the ancient course of the river and its volume. The nature and fossil content of the deposits of the river reflect the conditions under which the deposits accumulated. Non-river deposits which may be associated with those of the river can also help reconstruct the environment under which the river itself was formed. Examples of non-river deposits which are commonly associated with river deposits are the wadi and sand dune accumulations which usually interfinger the deposits of the river as well as the soils which develop on the surfaces which the river had left behind. These formations make excellent climatic indicators. Wadi deposits accumulate during wetter times while sand dunes form during more arid times. The nature of the soil is also determined to a large extent by the climatic conditions prevailing during the time of its formation.

Fluctuations of lake levels in the catchment area of the river are also useful in deciphering the climates of the past; lake levels rise when the rainfall increases and fall when it decreases. In the case of the Nile the presence of a depression near its course at Fayum makes it possible to estimate the amount of water the river carried in its past. The depression was filled when the Nile water rose to a height that allowed it to override the divide separating it from the depression forming a lake that rose to heights that were determined by the amount of water that it received and the duration of the connection to the Nile. The successive lakes that occupied the Fayum depression are evidence of the fluctuations in the height and discharge of the river in the past.

Eyewitness accounts of past social and economic conditions of the country and its people are helpful in revealing the nature of past fluctuations of the river. These assume particular

significance in the case of Egypt whose economy, as late as the mid-years of the twentieth century, was based on agriculture which depended solely on the Nile. Prior to the building of the great irrigation works of the nineteenth century the prosperity and survival of Egypt depended on the height of the flood which had to be within a limited range and to last for a specific duration to allow for the inundation and soaking of the land and the maturing of the crops. A bare change of 1.5 meters in the level of the flood could make the difference between a low Nile unable to override the land, which would then be left uncultivated, and a disastrously high Nile which could wash away the entire irrigation system. Despite the predictability of the river, a single failure of the flood to be within that range could cause enormous misery and could leave an impact on the psyche of the nation. Thus historic documents describing these events and recording famine chronologies are invaluable in deciphering the behavior of the Nile in former times. In the case of good governments which stored grain surpluses in years of good Nile to dispense them in years of poor Nile, conditions became worse only when there were two or more consecutive failures of the Nile.

It is not surprising, therefore, that the annual flood of the Nile, has been watched and recorded since antiquity. Many of these records have been lost, but some have now been recovered from ancient and medieval Egypt. Enough records of the renowned Roda gauge near Cairo have remained from the time of the Arab entry to Egypt to form a valuable series of maxima and minima of the river. These have been collected and edited by numerous authors. All surviving nilometers are from the late Pharaonic and Ptolemaic times; they were all constructed in conjunction with a temple precinct. They have been described and their plans surveyed (Borchardt 1906, 1934). In addition to serving as measures of the height of the river, the nilometers probably also served to bring the Nile within a sacred area for use in liturgical rites (Bonneau 1964). Typically these structures consisted of a covered stairway leading down from high ground to depth equal to the local low-water level of the Nile. River water was channeled in at an opening at the bottom, either directly or by means of infiltration through the soil; it was then able to rise freely along the enclosed staircase until it reached the same height as the river outside. Very often scales on the walls above the steps served to measure the height of the water; at a few places movable measuring devices were used. These latter are known to have been used during the Graeco-Roman period. Ordinarily the devices were kept in the temple when not in use (Tousson 1925).

In the case of the Karnak temple, the nilometer was not placed within the temple precinct but just outside where it was built into a quay which was connected with the west outer wall of the temple and, therefore, was accessible to more people.

6.1. The Holocene (Nabtian) Wet Phase

As mentioned in Part I, the regimen of the modern Nile was established some 10,000 years ago at the onset of the Holocene (Nabtian) Wet Phase which seems to have affected the sources of the Nile, increased its flow and established the present regimen of the river as we know it today. This phase is known as the Holocene Wet Phase because of its occurrence during the Holocene or the Recent Epoch. It is also named the Nabtian Wet Phase after the Nabta Playa where dated deposits of this phase are best described and exhibited. The Nabta Playa lies in the south Western Desert of Egypt, some 300 kilometers to the west of the Abu Simbel temple (Fig. 3.7). The Holocene Wet Phase affected the entire Sahelian belt which extends along latitude 15°

North from the Senegal River to the Nile River and falls today within the 100 to 500 millimeter rain zone (Fig. 2.11). During the Holocene Wet Phase the isohyets (or lines of equal rainfall) of the Sahel belt shifted northward 8 to 10° of latitude expanding the rain front and increasing precipitation over large parts of the Sahara, converting it into a much more verdant land. Many lakes, which have since disappeared, studded the dry Saharan landscape. During that phase the discharge of the rivers was larger and the level of the lakes that survived, such as Lake Chad, was higher.

The presence of an early Holocene wet interval has been recognized for a long time from the abundant lake deposits and associated archeological sites noted all over the barren deserts of the Sahara. The results of these early exploration works are summarized in the extremely readable papers of Ball (1927) and Murray (1951). In recent years the study of this wet interval has received great attention, in part, because of the concern over the recent Sahel droughts produced by the shifting patterns of rainfall. Valuable paleoclimatic, archeological and paleoenvironmental data are now available as a result of the research conducted by interdisciplinary teams that have been working for the past 25 years in Algeria, Tunisia, Libya, Egypt, Sudan, Tchad, Mauretania, Niger, and Senegal.

Dated geological events in the eastern Sahara indicate that the Holocene (Nabtian) Wet Phase lasted for more than 6500 years from about 10,000 years ago to the middle of the fourth millenium B.C. when the phase ended. About that time rain ceased to fall on the low-lying stretches of the desert to the east and west of the Nile, desert conditions began to spread and the long parallel dunes which now streak the Western Desert of Egypt set out on their long march. East and west of the Nile the grass and scrub slowly vanished, the trees withered, the game migrated, and the last of the survivors of the civilization of cattlemen and hunters which once flourished around the verdant playas of that desert abandoned the drying plains raiding the valley of the Nile.

The rains of the Holocene (Nabtian) Wet Phase were felt first in the southern reaches of the Sahara from where they moved northward toward the middle latitudes of Egypt. In Egypt and the eastern Sahara the rains were not large and probably never exceeded 200 millimeters a year as evidenced by the faunal remains described from the numerous archeological sites of this age. The Egyptian Sahara was indeed a desert albeit less forbidding than today. Van Neer & Uerpmann (1989) list these faunal remains, give the basic ecological requirements and modern geographic range of each of the species described.

The areas of the sources of the Nile, however, seem to have been considerably wetter during most of the duration of the Nabtian Wet Phase. The Nile was a mightier river carrying a discharge many times its present-day discharge. It tapped new catchment areas in Nubia, northern Sudan and the Eastern Desert of Egypt that do not contribute any water today. These new areas added to the discharge of the river through their activated wadis. The increased Ethiopian rains also added more water especially along the Atbara.

During the Holocene Wet Phase there were short spells of aridity which seemed to have left an impact on the settlers of the deserts of Egypt. There were at least four of these short arid episodes each lasting between 100 to 200 years. These arid episodes alternated with wetter episodes the duration of each of which varied from 500 to 1500 years. Hassan (1986) reviewed the detailed work carried on the deposits of the Holocene Wet Phase of the Nabta playa. Below are the dates of the dry episodes which interrupted this phase in that area:

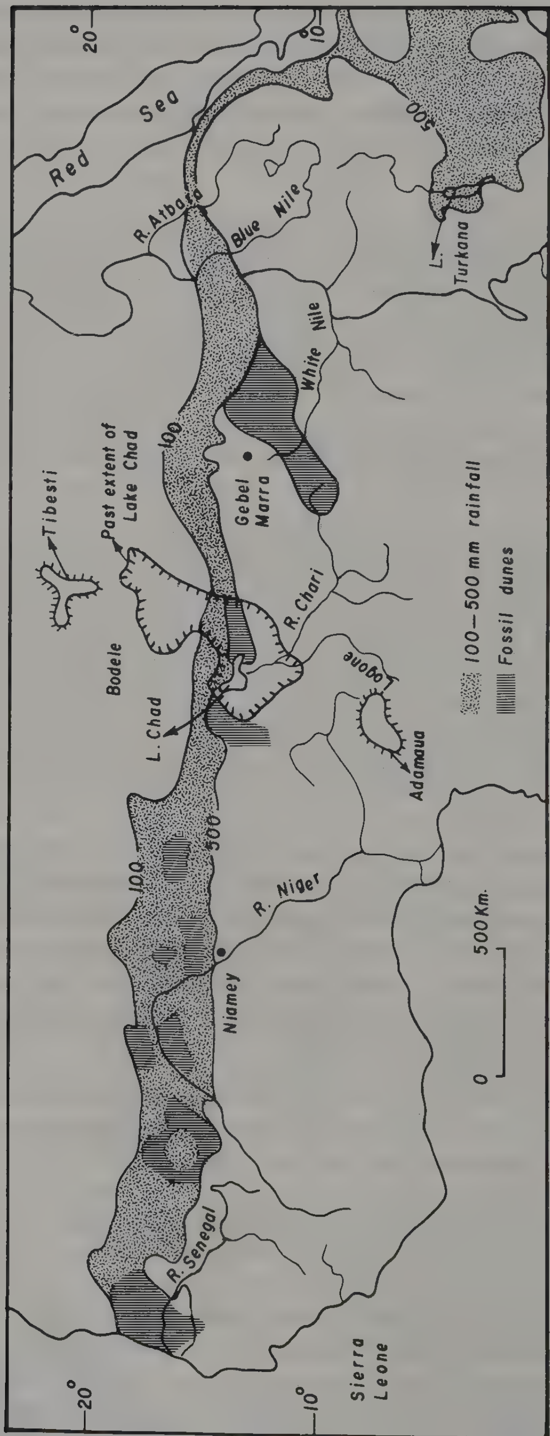

Fig. 2.11. The Sahel zone.

6100–5900 before present (5025–4785 B.C.),
7100–6900 before present (5975–5740 B.C.),
8800–8600 before present,
9400–9300 before present.

Figure 2.12 is an attempt to show the Nile discharge estimates from the beginning of the Holocene (Nabtian) Wet Phase to the end of the Late Period of Ancient Egypt. The discharge amounts given are rough figures especially for the earlier part of the Holocene Wet Phase when they must have been considerable. Starting with Ancient Egypt there are records, albeit fragmentary, which make possible the estimation of the discharge of the river at least in relative terms to recent records.

The discharge estimates of the early part of the Nabtian Pluvial are based on the height of the Nile during that period as reported by the archeological expeditions that have been active in Nubia and Egypt since the 1960's. The work of the Combined Prehistoric Expedition in Nubia shows that the Nile was high some 9400 years B.C. (Heinzelin 1968). It rose to a level of 13 meters above the modern floodplain in Nubia. Since the ground level in Nubia at that time was about 3 meters higher than at present (see section 6.3.4, Part I), it follows that the river must have stood about 10 meters above its bed. This large rise in the water level can also be detected further north where the river was able to override the Hawara channel and gain access to the Fayum depression inspite of the fact that the flood plain of the Nile was about 5 meters lower than at present. The newly-formed lake, the Paleomoeris, lost acces to the Nile and seems to have dried up about 8000 B.C., and stayed dry for about 500 years during which time a soil formed on the surface of the exposed Paleomoeris sediments.

After a period of 500 years of low river, the Nile became high between 7500 B.C. and 6000 B.C. During that time it regained its access to the Fayum depression and formed two successive lakes, the Premoeris and the Protomoeris, which were separated from each other by a short period of recession. Proof that the river was high during this period comes from the high terraces it left behind. From the Old Kingdom fortress at El-Kab opposite Idfu a high terrace of the river dated between 7600 and 7200 B.C. was mapped and studied (Vermeersch 1978).

Evidence of a great flow of the river about this time comes also from the study of the Mediterranean offshore boreholes drilled opposite the Nile delta where layers of organic-rich sediment (sapropel) dated between 7600 and 7000 B.C. are reported at depth. The formation of these layers is taken to indicate a great flow of the Nile waters into the Mediterranean which must have had, under the influence of this flow, an hydrographic setup that inhibited thermocline convection and made possible the accumulation of layers rich in organic content. The assumed great flow of the fresh waters of the Nile into the Mediterranean at that time prevented the sinking of the light oxygen-bearing surface waters to the bottom of the sea thus preventing putrifaction of organic matter and allowing it to be preserved.

For 800 years between 6000 and 5200 B.C. the river must have been low. Its connection with the Fayum depression was severed; the lake must have dried up and the region must have been deserted; there is no evidence of human occupancy of the depression during this period. We owe this most interesting discovery to the work of the Combined Prehistoric Expedition (Wendorf & Schild 1976). A similar hiatus in the archeological record is also noticed in the Nile Valley. This hiatus does not seem to have been due to the desertion of the valley, as was the case in the

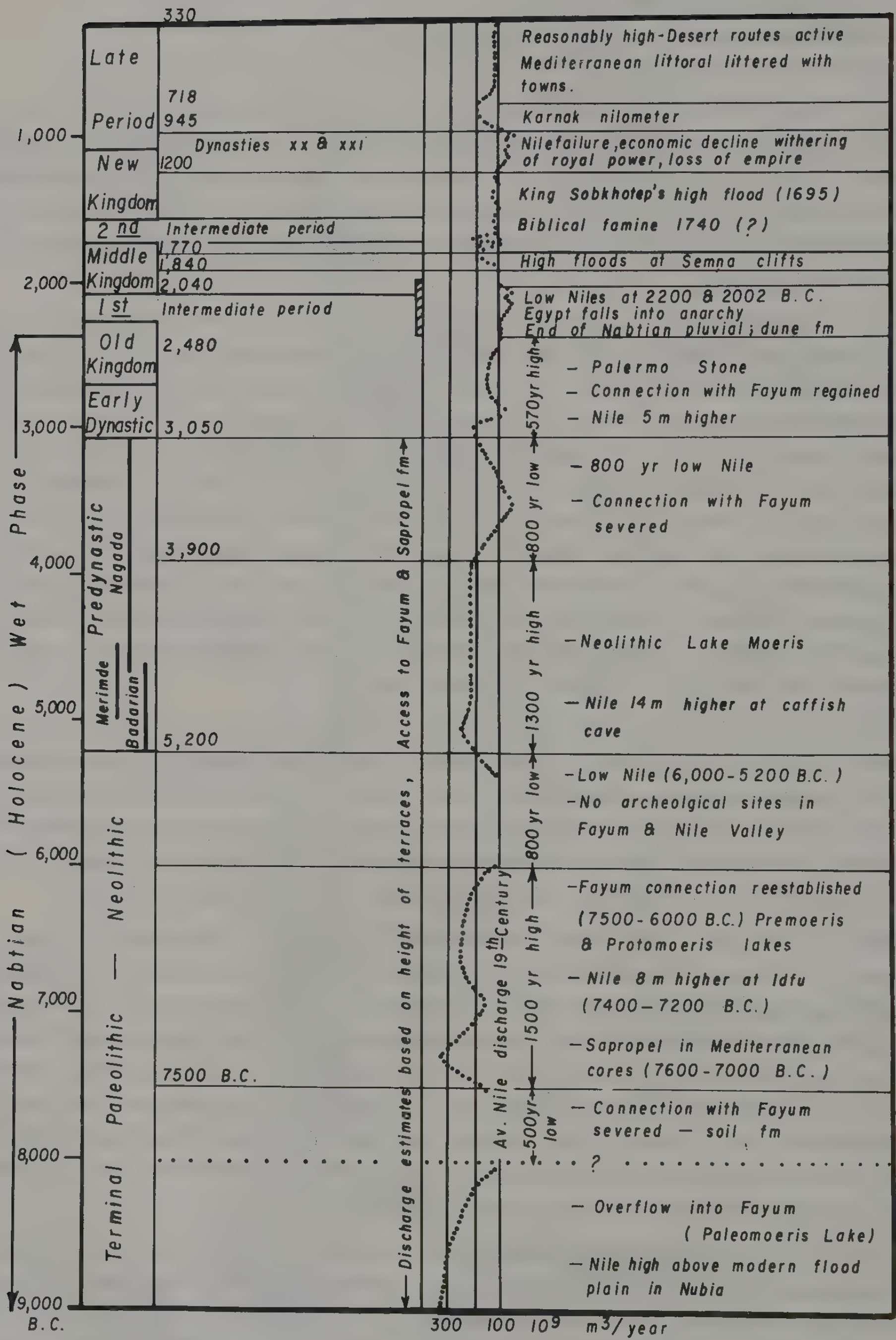

Fig. 2.12. Nile fluctuations from ca. 9000 to 332 B.C.

Fayum, but rather to the burial of the sites of the settlers of the valley who were forced to follow the river as it dropped during this period and to settle along the lowered banks of the river. These sites were destroyed and buried during the succeeding periods of higher Niles (Hassan 1988).

Around 5200 B.C. the river seemed to have had a series of high floods that raised its level to 16 meters above the modern floodplain, inundating the floor of the "Catfish Cave" which stood at that height along the cliffs of Egyptian Nubia. The floor of the cave was found to be covered with Nile silts with which were associated an occupation floor with abundant fish remains. These remains were conspicuous and gave the cave its name (Wendt 1966). During this period of high floods the river gained access to the Fayum depression and formed a lake which registered the highest levels ever (19–24 meter beaches). For 1300 years (5200–3900 B.C.) the river was generally high. It then became low starting from 3900 B.C. when the connection with the Fayum was severed again; it was regained around 3000 B.C.

Evidence of a high Nile during most of this early phase comes also from the Sudan. Geomorphology shows that as late as 3000 B.C. the floodplain of the Main Nile at Khartoum was about 5 meters higher than at present and that between 10,000 and 6000 B.C. it was higher still (Desmond Clark 1984). At that time also, as the annual flood waters receded, the White Nile formed an extensive swamp or lake with many ephemeral, and some permanent, ponds or swampy areas on the clay plains between the White and Blue Niles. Paleobotanical and faunal evidence suggests that around 6000–5000 B.C. gallery forest with much associated grassland was an important feature of the main valley and the land between the Blue and the White Niles. In addition, there is evidence, as in Egypt, that about 5000 B.C. there was an onset of drier conditions ending in the disappearance of the White Nile lake and the downcutting of both the White and Blue Niles.

In conclusion, it can be said that during the 6400 year span of the Holocene Wet Phase the Nile passed through several cycles, each averaging between 1300 and 1500 years, in which it was high. These were separated by cycles of low Niles each of which lasted between 500 and 800 years. These long period cycles must have had many fluctuations of shorter periodicity within them. But these are difficult to discern with our present state of knowledge. Further research is needed in order to work out the details of these major cycles of long period variability.

6.2. Nile Fluctuations in Ancient Egypt

From early historic times the Ancient Egyptians regularly measured the maximum height of the yearly flood and recorded the level in their royal annals. The surviving records are difficult to interpret since the various measuring devices employed in different periods did not use the same zero point, and most certainly not the same scale. Some of these records, as well as the literary documents of Ancient Egypt describing the social and political conditions which reflect on the state of the Nile, have been recently subjected to intensive studies (Bell 1970, 1971, 1975; Butzer 1974, 1976). The papers by Bell include extremely valuable information which was freely used in preparing this section. The subject of flood levels of the Nile in Ancient Egypt is currently under study by a working group in Göttingen under the direction of Professor Westendorf (Westendorf, Wolfahrt & Henfling 1989).

6.2.1. Old Kingdom records (3050–2480 B.C.)

The oldest records of the Nile floods were carved on a large stone stele during Dynasty V (2480 B.C.) and includes sixty three levels of flood which go back to the reign of King Jer (Zer) early in Dynasty I (ca. 3050 B.C.). The most valuable surviving fragment of this monument is the Palermo Stone (Fig. 2.13) named after the Sicilian capital where it is now housed in the museum. It is a mere fragment; other fragments, either belonging to the same monument or to one exactly resembling it in scale and arrangement, were later recovered from the Memphis area and are for the most part in the Cairo Museum. The Palermo Stone was first described and translated by Schäfer (Schäfer 1902). It is a 42x30 centimeters diorite stela whose original location is unknown, although most authorities assume it came from the Memphis area like the other fragments. The text of the recto of the Palermo portion is continued on the verso, and the whole must have formed a free-standing oblong stela erected in some temple so as to be visible alike at front and back. Both sides are divided horizontally into registers or rows; these again are divided vertically into compartments each carrying its own hieroglyphic legend. The top row of the recto enumerates the bare names of Predynastic rulers whose lengths of reign and whose doings are presumably unknown. The other rows inscribe the doings of the kings of Dynasties I to V whose names as well as those of their mothers appear between the rows. The compartments under each king mark his doings during each year of his reign, and below each compartment is given an indication of the height reached by the Nile inundation in that particular year. The height is indicated in the units of measurement of Ancient Egypt: cubits, spans, palms and fingers.

A list of the flood levels inscribed on this stone and on the Cairo fragments, which total about 91 levels, have been compiled by Helck (1966) and have been converted to the metric system (according to the relation: 1 cubit = 7 hands/palms = 28 fingers = 2 spans = 0.524 meter). There are 43 heights given for Dynasty I of which seven are illegible. Of the rest 12 belong to King Jer, 15 to King Den and 9 to King Semerkhet. They average 2.8 meters in height. The highest record was that of the year 30? of the reign of King Den which registered 4.25 meters. There are no inscriptions in the line reserved for King Aha, the predecessor of King Jer, nor in year two of Jer himself, which could be taken as evidence of the intellectual honesty of those who compiled the text, since it would seem that they did not make up figures when they had no records of them.

Out of the 21 heights given for Dynasty II (ca. 2890–2686 B.C.), 13 were in the reign of King Nynetjer and 8 in the reign of King Khasekhemwy. The lowest record was in year 14 of King Nynetjer (ca. 2813 B.C.) when it registered 52 centimeters. From that year and until the end of Dynasty II and, in fact, until the fourteenth year of the first King of Dynasty III, King Nebka, low floods were frequent and the average of the floods went down from 2.8 meters in Dynasty I to the record low of 1.6 meters in this period. These were years that left an impact on the well-being of the nation. There are records of persistent civil unrest if not outright war, flimsy construction, less affluent times and a weakened economy. An increase in the height and a return to a more beneficient Nile with lesser fluctuations occurred during dynasties III–V (2686–2345 B.C.) when the Nile registered an average height of 1.8 meters. There was one record of 2.7 meters during the reign of King Snofru (Dynasty IV) and an average height of over 2 meters during the reign of King Djoser (Dynasty III). These records make suspect the Aswan (Sehel

Fig. 2.13. The Palermo Stone.

Island) Famine Stele (Fig. 2.14) which records a 7-year span of low Niles during the reign of King Djoser (Barguet 1953). This stele was inscribed during the reign of Ptolemy V (second century B.C.) some 2400 years after the event. The claim that it was based on an Old Kingdom original is also suspect. It is hard to believe that originals would be preserved for that length of time.

Taken as a whole there was a decrease from an average flood height of 2.8 meters during the years 3050–2813 B.C. (Dynasty I and the first 80 years of Dynasty II) to an average height of 1.6 meters during the years 2813–2672 B.C. (Dynasty II). This was followed by an increase to 1.8 meters during the succeeding four Dynasties (2672–2480 B.C.). Figure 2.15 plots the height of the individual floods recorded on the Palermo Stone.

Very little is known of the Memphis nilometer, frequently referred to in the classic literature as the House of Inudation, at which most of these readings are believed to have been taken and

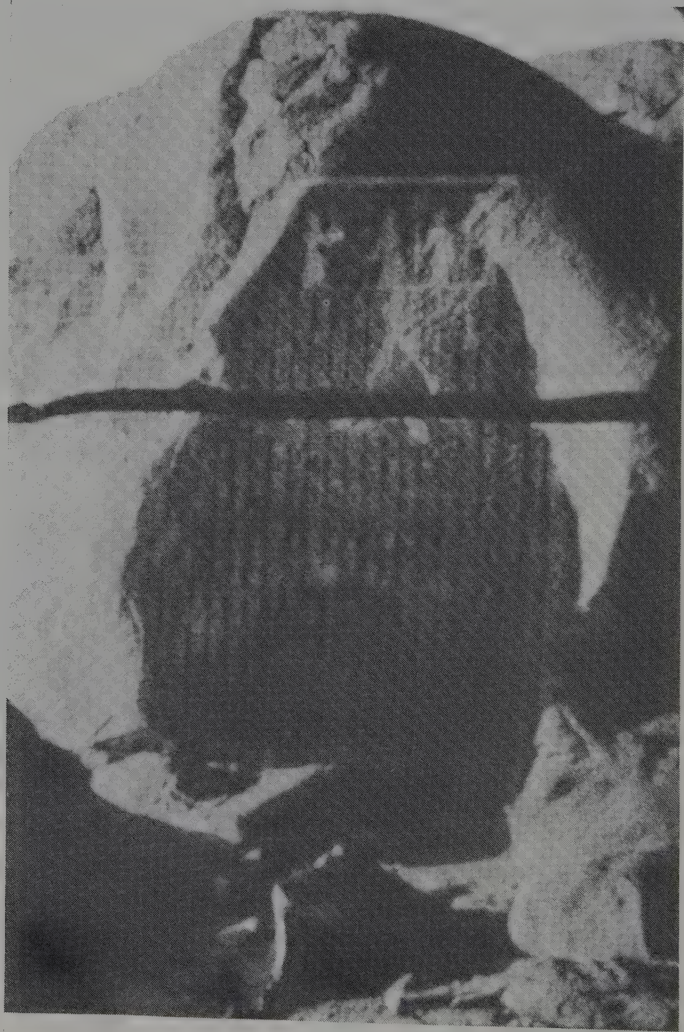

Fig. 2.14. Famine Stela at Sehel Island, Aswan.

of which there are no remains standing today. Judging from the low figures of the readings, amounting to less than half the levels in a well of a nilometer in the Cairo area, I hazard the conjecture that these readings represent the height of the flood waters measured from the floor of the Memphis basin. The zero level of the Memphis nilometer must have been at the level of the ground of the Memphis agricultural basin. In Aswan the Nilometer of the Chnum temple has two zero levels, a lower level corresponding to the low water level of the river and a higher level corresponding to the level at which the fields were watered (Jaritz & Bietak 1977). It is possible that the Memphis Nilometer had similar zero levels, and if such was the case then the flood levels recorded on the Palermo Stone must have been taken with reference to the upper level as I have suggested.

It is also possible that the readings were taken by a portable device in the basins themselves. At the time of the Arab conquest in 642 A.D. the readings of the Memphis nilometer were taken

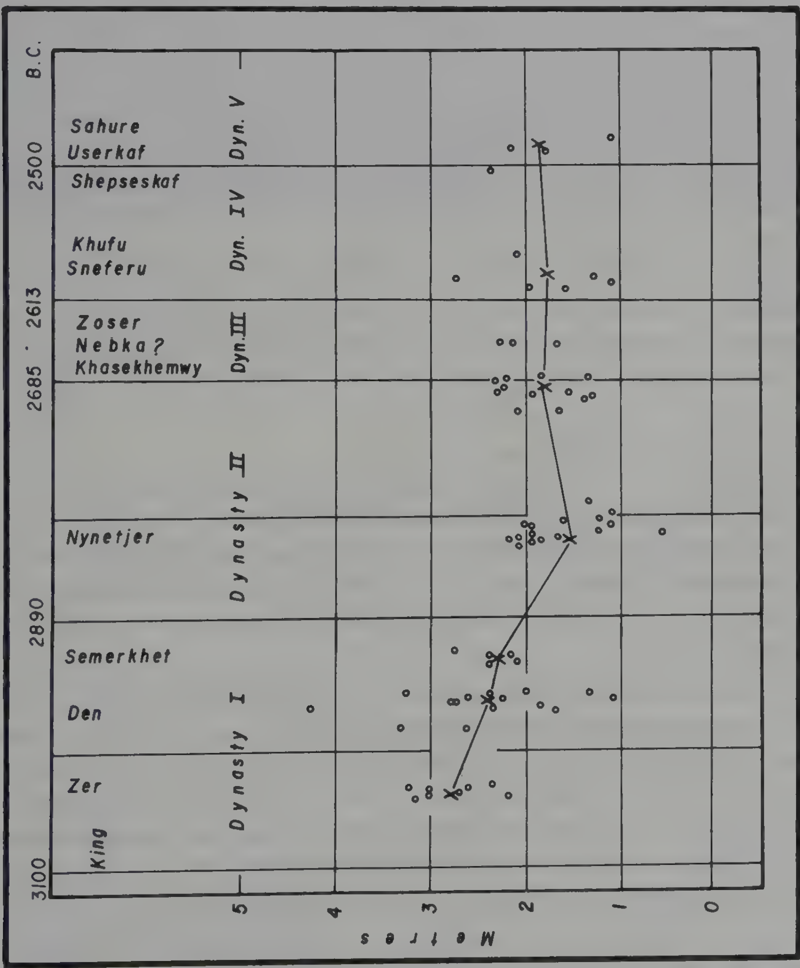

Fig. 2.15. Curve showing the fluctuations of the heights of floods of the Palermo Stone (modified after Bell 1970).

by a plummet. For a long time thereafter these plummet readings were ferried to Fustat to be announced and recorded (Jeffreys 1985).

Whatever the case may be the readings are indeed comparable to the flood levels in the Saqqara (Memphis) basin as registered in the nineteenth century when basin irrigation was still practiced. It would be feasible, therefore, to estimate the discharge of the river at the time of ancient Egypt by comparing the levels of the Palermo Stone with the levels of the flood waters of the Memphis basin in nineteenth century Egypt. Figure 2.17 is a cross section of the Saqqara (Memphis) basin during the high flood of 1887 A.D. (with a discharge of 119 billion cubic meters). The elevation of the floor of the basin averaged 20.2 meters above sea level and that of the flood level in that year 21.6 meters. Thus the water in the basin was 1.4 meters high. In 1878 A.D., which had the highest discharge on record (141 billion cubic meters), the flood level reached 22.2 meters and the height of the water in the basin was 2 meters. The flood of 1878 did not breach the western levee (embankment) of the river at Memphis, which has a height of 22.9 meters above sea level, but breached the eastern levee of the Damietta branch causing a great deal of damage to the delta region (Willcocks & Craig 1913). The height of the water in the basins during the nineteenth century A.D. floods is comparable to that on the Palermo Stone.

If one accepts the assumption that the levels of the Palermo Stone give the height of the flood in the Memphis basin, then one can assume that floods of the magnitude of 130 billion cubic meters (somewhere between the discharges of 1887 and 1878) were common during Dynasties III–V when the height of the water inundating the basin was in the range of 1.8 meters. In contrast, the floods of Dynasty I must have been some 50 percent higher and in the range of 200 billion cubic meters per year. The floods of Dynasty II, however, must have been in the range of 80 billion cubic meters such as those prevailing in the twentieth century. During Dynasty II such low discharges must have left a large part of the land uncultivated since no lifting devices were known and no elaborate system of irrigation was as yet in existence.

6.2.2. The low Niles of the First Intermediate Period

The Holocene Wet Phase terminated around the end of Dynasty V when the rains fell to their present-day level. After that there were periodic fluctuations in the amount of rainfall affecting the Sahelian region and the sources of the Nile, but there was no repeat of the great and sustained rains of the earlier times. The Nile discharge was reduced to averages hovering around those of the present time.

The effect of the end of the Holocene Wet Phase was felt not only in Africa and the Sahelian region but also in many Middle Eastern countries. About the time of the end of the wet phase or shortly thereafter the Akkadian Empire disintegrated; Troy II, Byblos and other sites in Syria and Palestine were destroyed, and the Early Bronze Age ended by a catastrophe in western Anatolia (Bell 1971). A decline in the rainfall seems to have had an adverse effect on the economic base of many of the civilizations of the area extending from Greece to Mesopotamia.

The end of the wet phase affected Egypt in many ways. The desert started to assume its present character, and there was a drastic change in its fauna and flora. The faunal and floral assemblages of ancient Egypt are known from an examination of the osteological and floral remains and from the faunal and floral drawings on pottery decorations, ivory carvings and tomb reliefs in ancient sites and tombs. The fauna and flora of Ancient Egypt are reviewed and

Fig. 2.16. The Nile at Abu Sir during Old Kingdom times as envisaged by Borchardt.

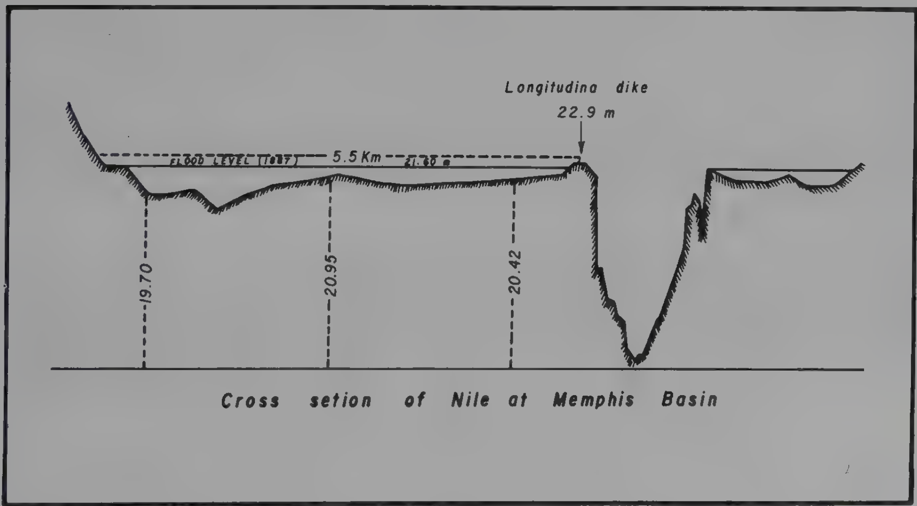

Fig. 2.17. Cross section at the Memphis basin (after Willcocks 1904 with modifications).

described in Boessneck (1988) and Täckholm (1976). There were two faunal breaks during the course of the gradual termination of the Holocene Wet Phase. In the first break, which occurred during the Predynastic dry spell, the elephant and giraffe were seriously decimated. In the

second break, which occurred during the time of Dynasties II–V, the elephant and the giraffe as well as the rhinoceros and the gerenuk gazelle became locally extinct. The lion and barbary sheep were severely decimated. The savanna fauna of Egypt died out before the Pyramid Age. Dynasties IV and V enjoyed the last remains of this moist interval (Butzer 1959). Figure 2.18 is a scene from the tomb of Ptahhotep (Dynasty V) showing the wide variety of animals which were still roaming the desert at large at that time. The lower scene of the figure depicts the hunting of a lion which was still to be found at that time in the deserts surrounding the valley. Starting from Dynasty VI hunting scenes became less common and, when depicted, show hunting in fenced enclosures. The tomb of Merekura (Dynasty VI) shows a hunting scene in an artificial reserve, perhaps the first in history. There was also a great decrease in the frequency of the rock paintings (petroglyphs) which adorn many cliffs of both the Eastern and Western Deserts of Egypt. I have picked from the many petroglyphs that were collected and commented upon by Winkler (1938) one (Fig. 2.20), which was inscribed in better times, showing the lush desert during the wet phase with a hunter drawing an elephant, a rhino, the kid of an ibex, an ibex, the kid of a gazelle and a gazelle. Below is an ostrich running with an enormous stride and lifting its wings.

There is also evidence of a change in the flora of Egypt as the Holocene Wet Phase came to an end. The desert during this wet phase was a parkland with numerous bushes, acacias and tamarisks. Tree roots of acacias and tamarisks were identified in many Predynastic desert sites. Some of the reliefs of Dynasty V tombs (Fig. 2.19) show a low desert landscape with sycamore and smaller bushes. These scenes became less common in later periods.

Fig. 2.18. Upper, hunting scene from the tomb of Ptahhotep; Lower, lion hunting, from the same tomb.

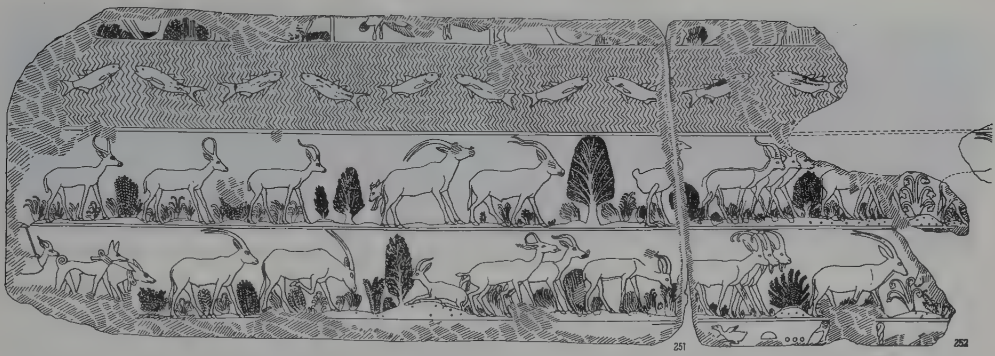

Fig. 2.19. Animal scene from the tomb of Ne-User-Re (after Edel and Wenig 1974).

Fig. 2.20. Rock painting on a shady wall near the sandstone cliffs of Shab el-Rigal, Nubia, drawn by a pebble, undated, ?Prehistoric or Predynastic (after Winkler 1938).

The end of the Holocene Wet Phase saw numerous waves of nomads driven out of the surrounding desert lands and settling in the Nile Valley out of necessity. Inscriptions indicate that many of them, especially the Libyans, did settle in the valley, finding employment with the army as mercenaries (Edwards, Gadd & Hammond 1971; Bell 1971).

The greatest effect of the end of the Holocene pluvial, however, was on the discharge of the Nile which seems to have declined until it reached a minimum ca. 2200 B.C. From then and for

Fig. 2.21. Hunger scene from the Pyramid of Unas causeway.

a period of 200 years the Nile fluctuated frequently; it dropped sharply for a number of successive years at least twice during this period. The first of these low periods followed the fall of Dynasty VI and lasted for ca. 50 years. The second episode came some 150 years later and lasted for about 12 years. There are no records of nilometer readings during these periods to verfiy the conclusion that the Nile was low; this was inferred from the historical events and from the large number of literary documents written during this period. The fact that Egypt during these times went through periods of disorder and total collapse can only be attributed to the destruction of the economic base due to the prolonged decline of the Nile. The specter of famine must have hovered in the air following the end of the Holocene Wet Phase. The first indication of it appears toward the end of Dynasty V when a relief from a causeway of the Pyramid of Unas (Fig. 2.21) depicts a group of severely emaciated people, evidently dying of hunger (Drioton 1942).

The first period of low Niles occurred around 2200 B.C. at the end of Dynasty VI when Egypt, until then a stable society, fell into total anarchy and entered with seeming suddenness into what historians call the First Intermediate Period and what Bell (1971) appropriately calls "the Dark Age". While the declining power of the late kings of Dynasty VI and the growing power and independence of provincial nobility were among the reasons for the disaster which overwhelmed Egypt at that time, there can be little doubt that the failure of the Nile for several decades must have set in motion forces beyond the strength of any authority to withstand. This period lasted from the end of Dynasty VI to the start of Dynasty IX (2200–2150 B.C.). The second period of disorder occurred during the last years of Dynasty XII starting from the middle of the reign of King Mentuhotep III and lasting for over a decade.

There are numerous texts which allude to the famines which afflicted Egypt during these decades. These have been the subject of studies by numerous authors including, among others, Vandier (1936).

Of special interest is the text of Ankhtifi, nomarch of Hierakonpolis and Idfu, whose inscriptions on his tomb at Mo'alla (30 kilometers south of Luxor), chronicle incidents of famine which occurred at the beginning of this period. One of the texts (translated from the French by Bell) reads: "all of Upper Egypt was dying of hunger, to such a degree that everyone had come to eating his children, but I managed that no one died of hunger in this nome. I made a loan of grain to Upper Egypt...I kept alive the house of Elephantine during these years, after the towns of Hefat (Mo'alla) and Hormer had been satisfied...The entire country had become like a starved (?) grasshopper, with people going to the north and to the south (in search of grain), but I never permitted it to happen that anyone had to embark from this to another nome...".

This text points to one of only two references of cannibalism in Ancient Egypt, an act of desperation that also occurred during famines in medieval Egypt. In other texts of the same period there is a clear reference to a low Nile such as the text of Khety, nomarch of Assiut, "when no water could be seen" and "when the land was as a sandbank (tzw)" or that of Neheri who "kept alive (nourished) his town during years of low Niles (tzw), who supplied it when there was nothing, who gave aid to it without making any distinction between the great and small...".

In numerous texts of this period there is mention of the frequency of sand storms and the accumulation of sand. This may be understood if we assume that with the advent of aridity, dunes started to form along the western fringes of the river. Ordinarily these dunes which form during the winter storms are flushed during the summer floods when these are high enough to wash the sand out. When the floods are low, dunes accumulate and encroach on the agricultural land. This seems to have been the case during this period when the longitudinal Khefoug dune field, which stretches for 175 kilometers (Fig. 1.24) along the western bank of the middle latitudes of the Nile, was probably formed. At present, this dune field is stabilized and is covered by a thin layer of Nile mud probably formed during the high floods of the period between 500 B.C. and 300 A.D.

The texts from the years 2002 to 1990 B.C. are replete with mention of crop failures, low Niles, drought, sandstorms and inability to survive. One letter written by a certain Heqanacht to his family, probably during the latter years of King Mentuhotep III, mentions that "it is better to being half alive than dying altogether. Now one should say hunger only in regard to real hunger. They have begun to eat people here."

The primary document on the confused and obscure period between the end of Dynasty XI and the start of Dynasty XII is the so-called prophecy of Neferty, composed during the reign of Amenemhet I (1991–1962 B.C.). There is mention of the black land disappearing and ruined and the "sun veiled by storm" (probably in allusion to the burial of the land under invading dunes); there is mention that "the river of Egypt is empty and that men can cross over the water on foot"; and there is a reference to "men searching for water upon which ships may sail" (probably due to the shifting of the bed of the river as a result of a lower supply of water).

Among the more interesting texts of this period of turmoil is the well-known piece of literature written by Ipuwer (now in the Leiden collection) describing the revolutionary atmosphere of the time: "He who possessed no property is now a man of wealth. The poor man is full of joy . Every town says: let us suppress the powerful among us". It is replete with lamentations on the state to which Egypt had sunk, "The inhabitants of the delta carry shields...the tribes of the desert have become Egyptians everywhere...Indeed the plunderer is everywhere and the servant takes what he finds...Indeed the Nile overflows, yet none plough for it. Everyone says :"We do not know what will happen throughout the land"." Ipuwer's text is undated, but the conditions it discloses leave no doubt that it was written during this period.

6.2.3. The Middle Kingdom Nile and the period of high floods (1840–1770 B.C.)

Egypt enjoyed a period of prosperity and a strong central government during the reign of the kings of Dynasty XII which was founded by Amenemhet I in 1991 B.C. There is hardly any mention of famines; the Nile had become generous and good. With the exception of a 90-year period (1840–1770 B.C.) of exceptionally high floods from which Egypt seems to have

benefited, the floods were normal and “good”. A record of a “good” flood during the reign of Senwosret I (1971–1928 B.C.) showed a level of 21.5 cubits (11.3 meters) in Elephantine (Aswan) nilometer, 12.5 cubits (6.6 meters) at the “house of inundation” at Old Cairo, and 6.5 cubits (3.4 meters) at Diospolis (Tell Balamoun) in the northern Delta (Kees 1961; Bell 1975). These levels, like comparable modern nilometer readings, indicate the difference between the high and low water levels. However, the two figures given for the “good” flood of Senwosret I from Aswan and Old Cairo are not compatible, and one or both must have been read at gauges which had a different zero-point from the present gauges. While the Old Cairo and Diospolis figures are comparable to the figures of an average flood of the nineteenth century on gauges at the same locality, the Aswan figure is considerably higher than the nineteenth century average flood on the modern Aswan gauge. The average height of an average flood of the nineteenth century (1870–1899) in Old Cairo was exactly equal to that of the “good” flood of Senwosret I. In Aswan the height of an average flood of the nineteenth century (1870–1899) was 8.2 meters while that of Senwosret I flood was 11.3 meters, more than 3 meters higher. The Senwosret I level is also higher than the 1878 record flood by 1.45 meters.

The reading of Senwosret I’s flood on the Cairo gauge should be recalibrated to take into consideration the amount of lowering of the level of the Nile to the north of the Fayum depression which was used during that time as a reservoir and an escape for the floods of the Nile. It has been assumed that about 40 percent of the discharge of an ordinary flood of 600 million cubic meters a day would be diverted to the depression and would fill it to its capacity of 10 billion cubic meters (below contour 21 meters) in less than 40 days. The level of the water at the Old Cairo nilometer, which lay to the north of the depression, would then be reduced by one meter. The level of Senwosret I “good” flood should be, therefore, corrected by adding this meter. The closest reading on the Roda Nilometer to that of the “good” flood of Senwosret I (after taking into account the amount of lowering of the level of the Nile into consideration) is that of the year 1887 (with a discharge of 119 billion cubic meters) when the rise in the gauge registered 7.55 meters.

If we are to accept that the zero point of the Middle Kingdom nilometer in the Cairo area marked the level of the low water as in modern nilometers, then we can compare Senwosret I’s flood with the flood of 1887; both rose to the same height from the same reference point. If one accepts the conclusion, drawn from the Cairo nilometer reading, that Senwosret I’s “good” flood was close in volume to the flood of 1887, one would expect that both floods would have the same height at the Aswan nilometers. This, however, is not the case. The reading of the 1887 flood in Aswan was 8.85 meters, i.e. about 2.45 meters lower than that of Senwosret I’s flood (11.3 meters). This discrepancy can only be reconciled by assuming that the zero point of the Middle Kingdom nilometer must have been lower than that of the modern nilometer by this amount. It is possible that the lowering of the zero point of the old nilometer happened during the First Intermediate Period when the long period of low Niles seems to have forced a readjustment of the nilometers. The Aswan gauge lies in a rocky path of the Nile and is consequently more amenable for readjustment than the northern gauges which lie in alluvial lands.

A flood of 120 billion cubic meters per year is truly a “good” flood. It can bring large areas of the valley under cultivation. “Good” floods continued during the reign of Senwosret III (1878–1843 B.C.) when Egypt enjoyed one of its most prosperous and stable periods, securing its southern borders by having full control over Nubia.

The most interesting records of flood levels of the Middle Kingdom come from the Semna–Kumma area in Nubia when, between 1840 and 1770 B.C., exceptionally high flood marks were inscribed on the bordering cliffs of that constricted part of the Nile (Fig. 2.22). At least 27

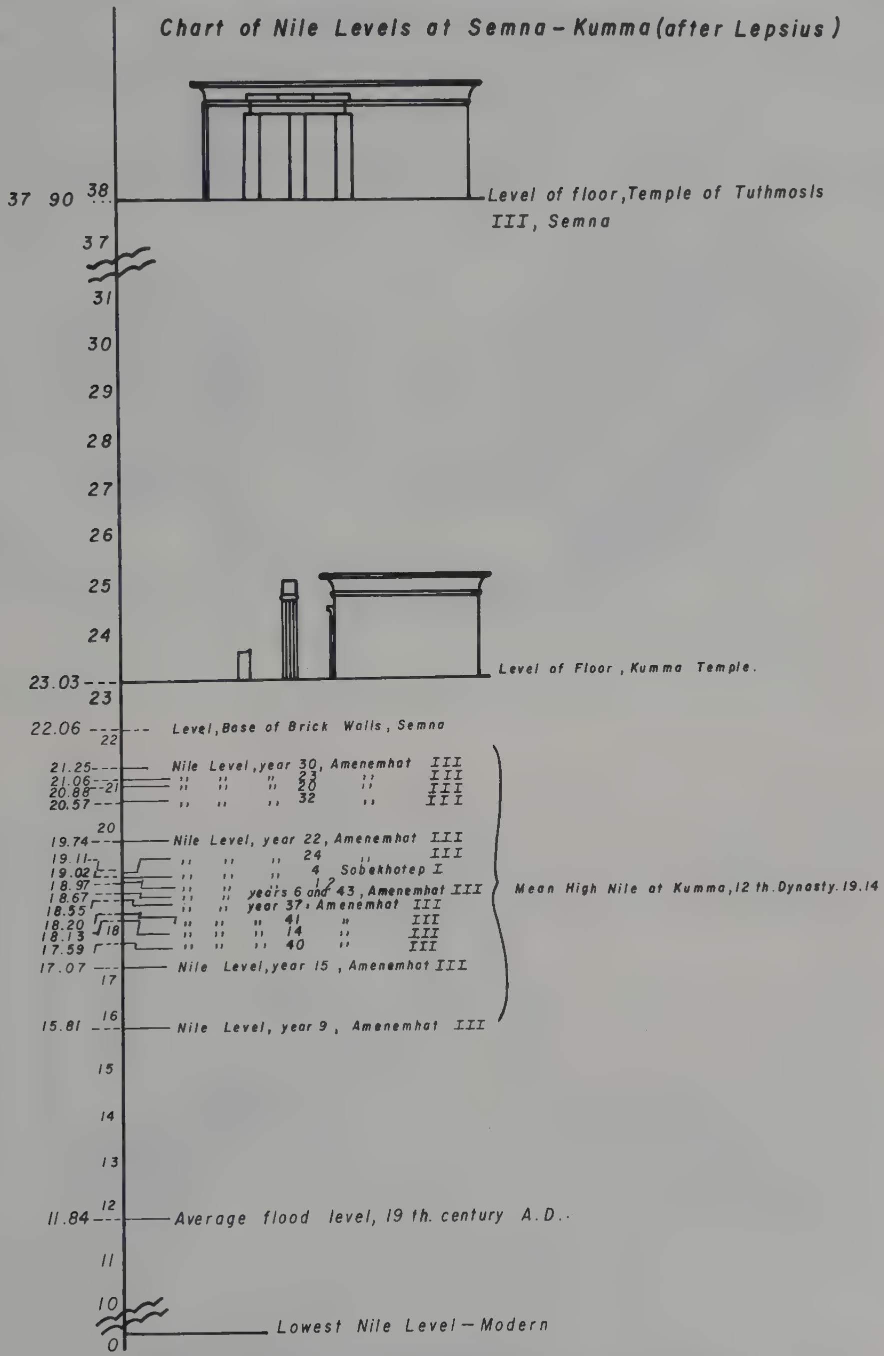

Fig. 2.22. Middle Kingdom flood elevations in the Semna area.

inscriptions are reported. They record floods 8 to 11 meters higher than those of today and imply flood volumes at least double the flood volumes of recent times.

Prior to its drowning by the waters of Lake Nasser, the 200-kilometer section of the Nubian Nile (from about 15 kilometers south of Halfa to about 14 kilometers south of Semna) was one of the most forbidding parts of the Nile (Fig. 2.23). It is occupied by the second cataract where the river is blocked at several places by barriers and little islands of igneous rocks, making navigation a hazardous undertaking. The most formidable of these cataracts are those around the Semna stretch where boats and men were lost during the Mahdi and the Sudan campaigns of the past century. At Semna, which lies some 137 kilometers south of Halfa, the Nile is crossed by a barrier of granitic rock which confines the river to a single narrow passage at low water,

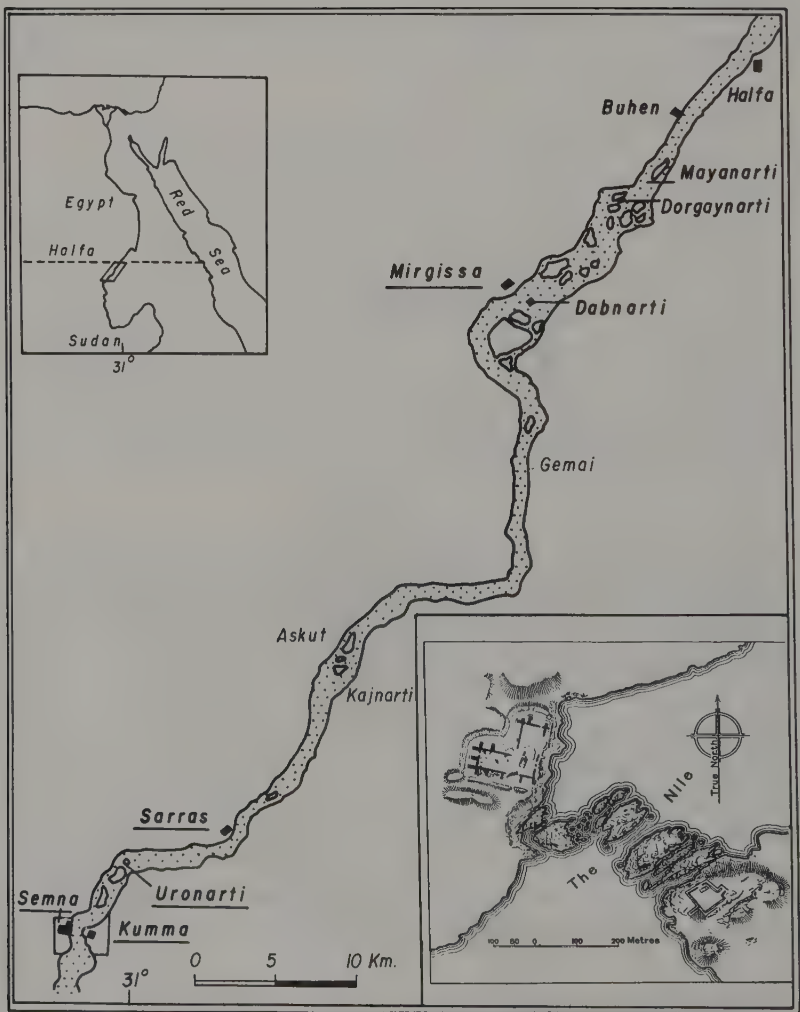

Fig. 2.23a. The Wadi Halfa–Semna reach of the Nile before the High Dam; lower right, the Nile at Semna.

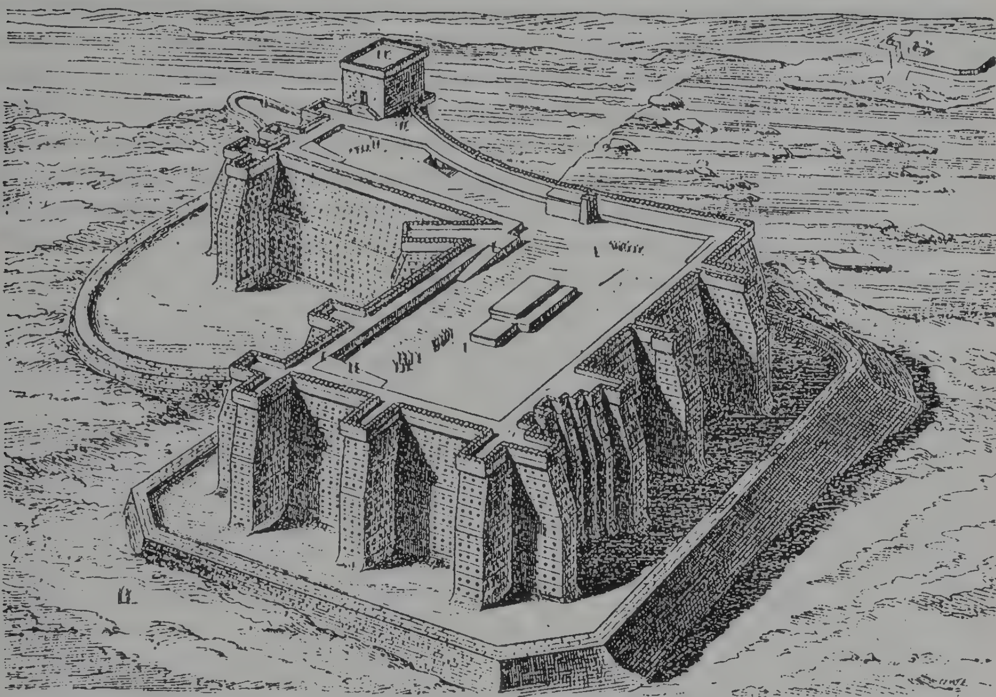

Fig. 2.23b. The Semna fort restored.

and to several turbulent rapids when the river is in flood (Fig. 2.23). The bordering cliffs rise to commanding heights on both sides of the river. On these prominent points the two fortresses of Semna and Kumma were built during Dynasty XII. They form a gateway controlling the traffic both by river and caravan route along the west bank; the latter passed through the fortress of Semna itself.

The interpretation of the Semna inscriptions, first reported by Lepsius in 1853, has been the subject of controversy. Some authors accept the flood levels at their face value and assume that they reflect exceptionally high discharges during the reign of Amenemhat III (Bell 1975). Other authors believe that the high levels were not due to a large volume of water passing through Semna but to a high river bed that has been eroded and lowered, since the reign of Amenemhat III, by at least 8 meters to its present level (Ball 1903). This view is difficult to accept for the staircases of the Semna and Kumma temples reach down to a level close to that of the low water of the modern Nile, indicating that the river bed at the time of the building of the temples was roughly at the same level as today. There is also the evidence coming from the choice of the sites of the New Kingdom forts which clearly show that they were built to fit a river that had the same elevation and regimen of the modern river in Nubia. The erosion theory, therefore, would lead one to accept the most implausible idea that the river lowered its bed by 8 meters in the short time between the Middle and the New Kingdoms.

Because there are no texts of any kind which refer to these exceptionally high floods in the Middle Kingdom annals, some authors postulate that the Semna–Kumma high levels must have been locally and artificially induced by a series of partial dams constructed to improve the navigability of the river in the difficult stretches of the Second Cataract (Vercoutter 1965). According to this idea the back water effect of these obstructions would have caused the raising of the water level in the Semna–Kumma constriction. Apart from a few blocks and spurs that are known to have been laid by the Ancient Egyptians along the banks of the Nubian Nile, there is no indication that enough constriction was made to cause this effect. King Ramses II of the New Kingdom is believed to have laid granite slabs around the Garf Hussein area to form a coffer dam while building his temple at this locality.

If one accepts the argument of Bell that the Semna–Kumma high levels mark an exceptional period of high floods, then the discharges of the river must have been great during most of the years 1840–1770 B.C. The estimation of the volume of these discharges is difficult; data about the cross section of the river and the duration of the flood are lacking. However, an approximate figure may be reached by comparing the high flood levels of the Middle Kingdom with those of the present-day gauge meters. The constricted nature of the valley at Semna raises the flood level to a greater height than in the downstream towns of Wadi Halfa and Aswan where the valley becomes relatively more open. Thus a flood level in Semna which is 8 meters higher than the 1902 flood level (the year John Ball visited the area) would read only about 4.3 meters above the flood level of that year in Aswan (which registered 6.72 meters). This would bring the level of the Middle Kingdom flood to about 11 meters above the low water level in Aswan, that is about 2.15 meters above the flood level of Senwosret I's "good" flood, and about 1.85 meters above the level of the highest ever recorded flood of 1878 A.D. This would make the discharge of the river during the period of high floods of the Middle Kingdom in the range of 180 billion cubic meters per year, that is about 130 percent larger than the 1878 flood of 140 billion cubic meters.

Floods of this volume have interesting consequences. In the first place their occurrence without causing great destruction means that Egypt during Middle Kingdom times must have learnt not only to live with high floods but also to benefit from them. The high floods increased the agricultural land and the wealth of the nation. This needed, however, a great deal of engineering work for the proper location of the infrastructure so that it may not to be reached by the floods, and for the regulation of the Fayum depression, which was inundated during this period of high floods, so that it may act as a safeguard against their destructiveness.

In the second place an explanation must be found for the occurrence of these high floods. Under the present-day hydrological regime of the river or its physiography, there is no way that floods of this magnitude can occur. They must have been the result of a total change in the climatic pattern and a return to the early conditions of the Holocene Wet Phase. The present-day physiography of the lower reaches of the Blue Nile, which is responsible for close to 70 percent of the flood, is such that in the exceptionally high floods the river below Khartoum overflows its banks and inundates large areas, such as happened during the high floods of 1946 and 1954 which were monitored with great alarm (Hurst, Black & Simaika 1959). The contribution from the Blue Nile, therefore, is limited in as much as any water beyond a certain limit will spill over its banks and overflow the stretch from Khartoum to Atbara, as recent observations have shown during the high flood of 1988 (Hulme 1989; Sutcliffe, Dugdale & Milford 1989).

The high floods must have resulted from new sources that the river must have tapped during this period of stronger northward penetration of the summer monsoon rains. This penetration resulted in increasing the Atbara supply, enlarging the catchment area of the river and activating numerous dry wadis of northern Sudan and southern Egypt both from the south, east and west. This explanation seems feasible as the exceptionally high floods of the past 120 years, of which we have records, were due either to prolonged and sustained floods lasting beyond the month of September (or beyond Holy Cross day, September 27, as referred to by older historians and especially the well-known nineteenth century historian El-Gabarty) or to an unusual high Atbara contribution. The former type of high floods is usually the more destructive. The prolongation of the high flood for a long time keeps the fields under water beyond the normal and proper season for sowing. Such abnormal duration of high waters could result in a poor harvest. Since all authorities agree that the reign of Amenemhet III was a time of high prosperity in Egypt we may infer that the great floods were not unusually prolonged as to interfere seriously with agriculture. This seems to indicate that the Middle Kingdom high floods were probably due to an unusually higher contribution from the Atbara River and from the wadis of northern Sudan and southern Egypt which were more active. Penetration of the summer monsoon north of the Atbara confluence, either to the east or west of the Nile, is not common. The only meteorological stations which might shed some light on the fluctuations of the rainfall in that area are those of Abu Hamad (Latitude 19° 32'; Longitude 33° 20'), Kerma (Merowe) (Latitude 18° 33'; Longitude 31° 51') and Tokar (Latitude 18° 25'; Longitude 37° 45') which registered an average annual rainfall (during the second half of this century) of 13.5, 31 and 90 millimeters per year respectively. In the high flood years of 1946, 1954, 1961 and 1963 rainfall records in the three stations were double and in some years triple that average. Evidence of similar increases of rainfall in antiquity in these areas comes from the time of King Taharqo (year six of his reign, 683 B.C.) when, "a down pour from the sky in Nubia made the hills sparkle", according to a surviving stele, and the flood was very great (Vandier 1936).

The 1988 exceptionally high flood was the result of a pattern of rainfall distribution that approximates that which could have brought about the high floods of Middle Kingdom times. The flood was due to an unusual northward penetration of moist air and rain over the Red Sea, Arabia and the Ethiopian Highland. Heavy rainfall occurred over the Blue Nile Basin and, in particular, over the upper Atbara basin activating many dry wadis. Daily rainfall of 200 millimeters was measured at Khartoum. Large areas between Khartoum and Abu Hamad on both east and west of the Nile received heavy rainfall (Hulme & Trilsbach 1989; Sutcliffe, Dugdale & Milford 1989).

6.2.4. Nile failures and economic decline, Dynasties XX and XXI (1200–945 B.C.)

There are few records and texts pertaining to the behavior of the Nile during the long time which elapsed from the death of Amenemhet III about 1797 B.C. until the ascent of Dynasty XX in 1200 B.C. During the beginning of this period Egypt slipped into poverty and disorder for two centuries until about 1570 B.C. The Hyksos were able to invade Egypt and occupy Memphis in 1674 B.C. founding Dynasty XV. This period, known as the Second Intermediate Period, is among the most obscure in Egyptian history, and texts are rare which could help unravel the conditions of the Nile at that time. The only documented famine during the Second Intermediate Period was that which is alluded to in a few texts discovered at El-Kab near Idfu (Vandier 1936;

Bell 1975), written around the year 1740 B.C. Since this is the only famine recorded during the period in which it is believed that the Biblical story of Joseph's coming to Egypt took place it is tempting to relate this famine to the Biblical famine (Genesis 47: 13–21). The seven consecutive years of this famine are said to have impoverished the Egyptians who were forced to give up their money, cattle, land and bodies in exchange for bread.

There seems to have been a repeat of the high floods of Middle Kingdom times during the reign of King Sobkhotep, the eighth king of Dynasty XIII (1703–1635 B.C.). In one record of this period (Habachi 1974), there is indication that the Nile was exceptionally high during the visit of the king to the Karnak temple when the Nile flooded the temple and the king came "wading" in. The floor of the temple today is 74.25 meters above sea level and the elevation of the ground around the temple is about 77 meters. As the land has risen by about 5 meters since King Sobkhotep's time as a result of the yearly accumulation of silt at the rate of 1.43 meters per thousand years (Ventre Pacha 1896), it follows that the elevation of the ground in King Sobkhotep's time must have been 72 meters above sea level (Fig. 2.24) and that of the low water level of the Nile 63.7 meters (that is 5 meters below the low level of the modern Nile). Assuming that the flood level of the Nile during Sobkhotep's visit to the temple was 74.5 meters (that is 25 centimeters above the ground level of the temple to allow the king to wade in), then the rise of the Nile in King Sobkhotep's visit must have been in the range of 10.8 meters. Such a rise would exceed the 1878 maximum rise on record by 1.7 meters and is reminiscent of the high floods of Middle Kingdom times which rose about 1.85 meters above the 1878 level. The discharge of the river must have been slightly less than the 180 billion cubic meters of the Middle Kingdom high floods. The height of the water in the basins was about 2.5 meters, a figure that is close to the height of the water in the Memphis basin during Dynasty I. However, it is difficult to draw any conclusions from this fact, for the Luxor and Memphis basins are distant from each other; it is certain that in one and the same flood season the height of the water in the basins of the south was higher than that in the basins to the north.

For about 330 years, from the rise of the New Kingdom to the last years of Ramses II (1570–1240 B.C.), the floods were normal, even slightly higher than the modern floods. In Nubia during the reign of Ramses II the flood levels marked one meter higher than those of today. A period of low floods followed; from 1200 B.C. and for a period of 255 years during the reign of Dynasties XX and XXI the Nile was generally low. This was a period of decline and increased political impotence; the empire was lost; royal power withered away; corruption became rampant and lawlessness, rioting and looting became common. This was indeed a "Dark Age" in the history of Ancient Egypt. There are records of at least two periods of civil war around 1139 and 1089 B.C. (Butzer 1984). The latter civil strife literally divided the country into two states run by the High Priests Herihor in Thebes and Smendes in Tanis.

Physical indications pointing to low Niles include the abandonment of agriculture in Nubia as early as the last years of the reign of King Ramses II as a result of the spreading of dunes over the flood plain and the development of thick salt encrustations (Heinzelin 1968). Lower discharges seem to have been responsible also for the silting of the western Pelusiac branch of the delta and the abandoning of the Ramesside capital of Avaris (Tell el-Dab'a) to Tanis on the Tanitic branch around 1200 B.C. The social function of the temple granaries changed. They were no longer applied for community redistribution but rather for private gain (Butzer 1984). During the rule of Ramses III the granaries of the new foundation of Medinet

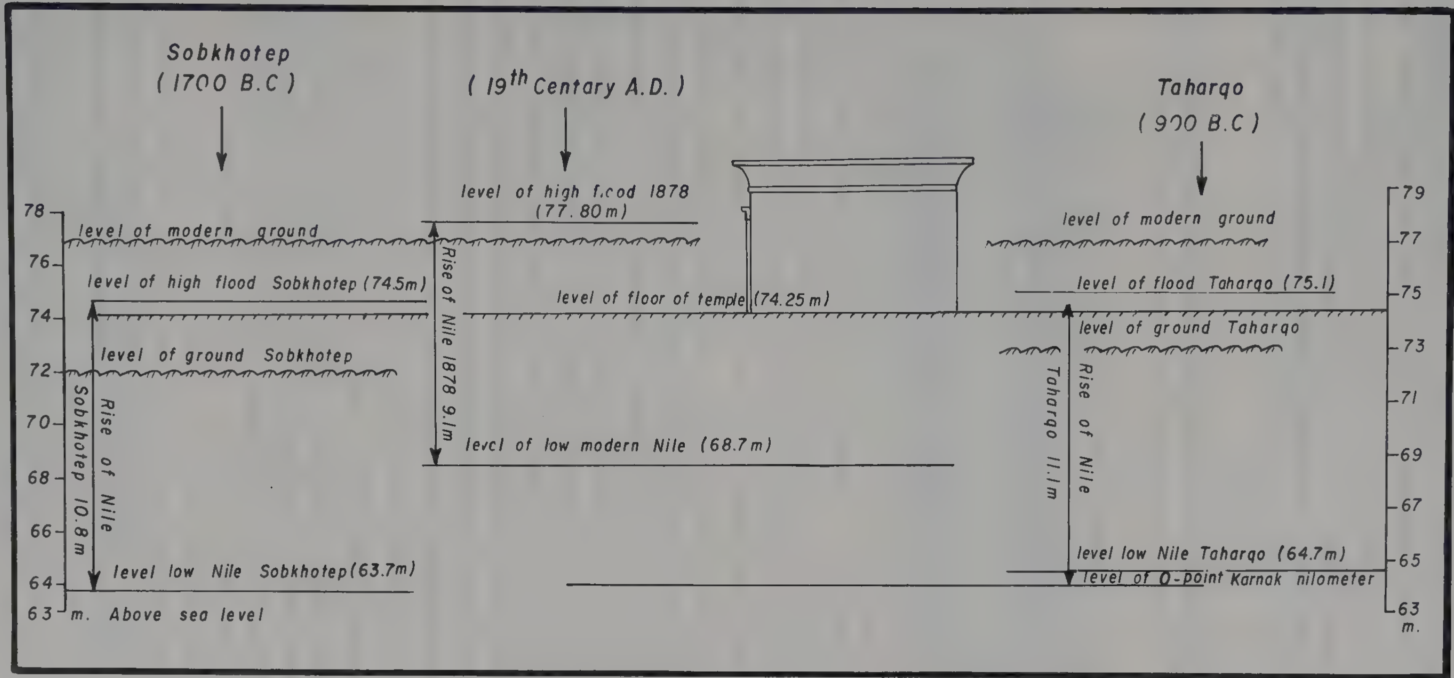

Fig. 2.24. Estimated levels of ground, low water and flood levels in meters above sea level at the Karnak temple, Luxor, during (a) late 19th century A.D. (b) Taharqo's time (900 B.C.) and (c) Sobkhotep time (1700 B.C.).

Habu were walled, showing that they were not safe and were frequently assaulted and looted despite the sanctity of the place. Documents from this period tell that in the twenty nineth year of Ramses III (about 1169 B.C.) the state labor corps often received its rations only after great delay and that this led to demonstrations of protest such as those which occurred on the tenth day of the month of Mechir by the disgruntled workers (Kees 1961). More rioting is reported, at least six times during the 50 years which followed. The period also was one of great inflation; grain prices increased after 1170 B.C. to eight fold and occasionally to twenty-four fold (Cerny 1954).

Libyan incursions became common during this period and exhausted Egypt until it finally was run over by the Libyans who established Dynasties XXII and XXIII.

6.2.5. Nile level records at Karnak, Dynasties XXII–XXVI (945–525 B.C.)

Records of Nile inundation levels are engraved on the quay of the Karnak temple. They were published and have been commented upon by many authors since the latter years of the nineteenth century (Legrain 1896; Borchardt 1906; Beckerath 1966). Ventre Pacha (1896) lists all the flood level marks on the nilometer and compares them with the flood levels of the nineteenth century. There are 45 Nile level inscriptions running from the reign of Shoshenq I to Psammetik I (Dynasties XXII–XXVI). The quay, which lay at the end of the avenue of the sphinxes, can be seen today at the foundation exposed at the ditch which lies at the modern entrance of the temple (Fig. 2.25). The elevation of the zero point of the nilometer was fixed at 64 meters above sea level. The highest record on the quay is that of year six of King Taharqo when the Hypostyle Hall of the Karnak temple was flooded and the water level therein reached 84 centimeters above the floor of the hall, i.e. 75.1 meters above sea level (the level of the Karnak temple is 74.25 meters above sea level). This means that the flood level of that year rose 11.1 meters above the zero point of the Karnak nilometer (Fig. 2.24). This level is 2 meters higher than the flood of 1878, the highest flood on record in modern times. The height of Taharqo's flood points to a larger discharge than that of 1878 (141 billion cubic meters) and could have easily exceeded the 180 billion cubic meter mark. If we are to accept the estimate of Ventre Pacha that the Nile flood plain has risen 4 meters since Taharqo's time (at the rate of 1.43 meters per thousand years) then the level of the ground at Taharqo's time must have been around 73 meters above sea level. This would indicate that the height of the water in the basins of Thebes was about 2.1 meters (Fig. 2.24).

The rise of the floods recorded on the Karnak temple quay ranges from 11.1 (year six Taharqo) to 9.22 meters (year ? of Smendes). The lowest year exceeds the highest year in the nineteenth century records. The period must have been one with exceptional floods. The years marked "joyful" were the years which had an average flood rise of about 10.6 meters.

6.2.6. The Nile from 500 B.C. to 600 A.D.

The few records available from the succeeding millenium up to the entry of the Arabs into Egypt indicate that the Nile was high with the exception of the latter years of the sixth century and early years of the seventh century A.D. Herodotus (ca. 450 B.C.) described Egypt during flood time as a sea. With the exception of a few years, the Ptolemaic and Roman years were plentiful. Most of the records of complaints and lamentations that we have from this period are

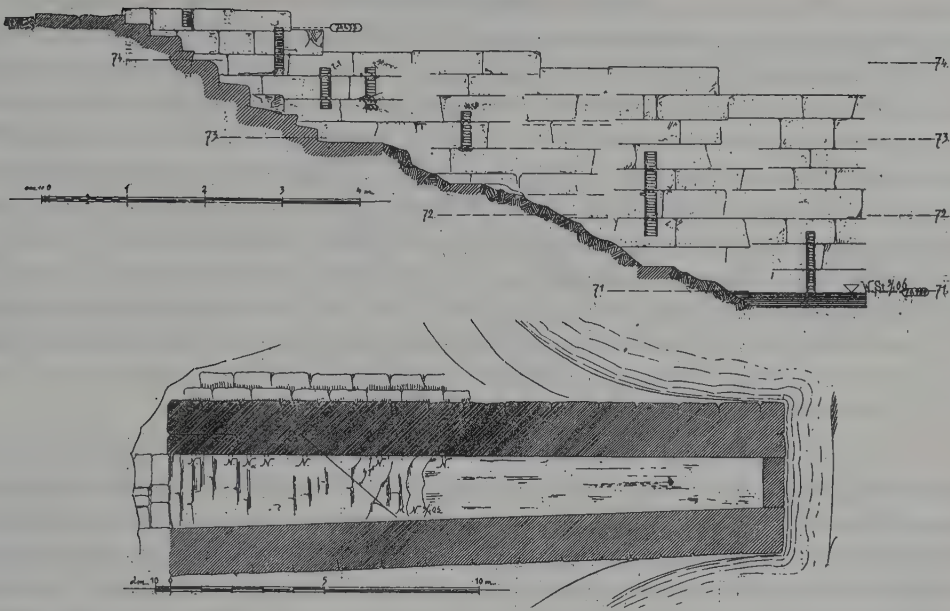

Fig. 2.25. Luxor Nilometer. Upper, staircase and scale; Lower, ground plan (after Borchardt 1906).

not famine related. Civil strife probably caused by famine did occur, however, during the reign of Ptolemy III (241–221 B.C.). A recently published papyrus provides indirect evidence of a disastrously low flood in 99 A.D. Pliny the Elder in his *Natural History* (as quoted in Lewis 1983, p. 110) mentions that the lowest recorded rise on the Aswan gauge was 5 cubits in 48 B.C. and the highest was 18 cubits in 45 A.D. This range is difficult to correlate with that of recent floods as recorded on the modern gauge at Aswan; the lowest and highest readings are those of the low flood of 1913 (5.22 meters or 9.66 cubits on the modern scale) and the high flood of 1878 (9.85 meters or 18.25 cubits on the modern scale). Even more difficult to correlate with the modern Aswan scale are the levels inscribed on one nilometer at Elephantine and given by Pliny the Elder (Lewis 1983), which read: Year 25 of Augustus Caesar (5 B.C.), 24 cubits, 4 palms and one digit; Year 13 of Nero Caesar (67 A.D.), 24 cubits, 6 palms and one digit; Year 10 of Domitian Caesar (91 A.D.), 24 cubits and 4 palms and Year 14 of Trajan Caesar (111 A.D.), 25 cubits. These readings are very high; they would measure more than 3 meters higher than the maximum level recorded on the present-day scale. The modern Aswan gauge is graduated into cubits, each cubit is 54 centimeters long and the zero level of the gauge has an elevation of 84.16 meters above sea level. It is possible that the zero level of the old gauge was considerably lower than that of today, but even if we take it to be at the same elevation as the zero level which we presumed for the Middle Kingdom nilometers (see section 5.2.3., this part), the floods would still be very high, almost 1.5 meters higher than the present-day floods.

During most of the Ptolemaic and Roman times the deserts of Egypt were extremely active. There must have been enough rainfall to make the desert a considerably more hospitable place than it is today. There was an active mining and quarrying industry in the deserts of Egypt: gold,

emeralds and ornamental stones were extracted on a large scale. The Indian trade crossed the deserts of Egypt to the Red Sea port of Berenice (which lies at the latitude of Aswan). This port assumed importance after most of the trade of Leukos Limen (modern Quseir) was moved to it because of the difficulty of navigating the Red Sea against the north wind, forcing a move from this northern port to Berenice. There was a great increase in the Red Sea trade when it was discovered that the monsoons enabled ships from Berenice to sail to India. To protect and assist the caravans, forts and watering stations were built along the routes by Ptolemy Philadelphus, so that in certain seasons the desert became thronged with traffic. All the harbors were connected to the Nile Valley by routes radiating out from Idfu or from the great bend of the Nile at Qena, Qift, and Qus. An indication that the climate must have been mild was that elephants, which were used in war during the Ptolemaic period and which were imported from India and the Sudanese coast, were driven along the Berenice–Idfu road. A survey of the old desert routes during Roman times is given in Murray (1935, 1967) and in Said (1989).

The northern littoral of the Mediterranean, which was until recently a deserted area, was littered with towns and villages which extended from Alexandria to Cyrene. There were cultivated fields and vineyards which were irrigated by an elaborate system of rock-cisterns. The town of Abumina (St. Menas), with its great basilica built by Arcadius ca. 400 A.D., does not seem to have been abandoned until about 900 A.D. Trans-Saharan traffic was active and was carried by the horse; the camel had not yet been adopted by most traders. By the fifth century B.C. a regular, if limited, trans-Saharan traffic had developed. Routes from Egypt, Cyrenaica and Tripolitania converged in the land of the Garamantes whose capital was Garama (Jerma) in the Fezzan. From Fezzan a regular route ran southwest through the Hoggar Mountains to the River Niger bend.

It is almost certain that it was lesser rains that contributed to the desertion of this area. We have a record of rainfall for the Alexandria area from the second century by Claudius Ptolemy, the geographer, showing that the total number of rainy days was then much the same as at present, but that these days were more evenly distributed throughout the year. Below are the actual records of rainfall as given by Claudius Ptolemy (after Murray 1935):

	Rainy days	Mist, drizzle	Mean at present day
January	4	1	11
February	3	–	6
March	–	1	5
April	5	3	1
May	3	4	1
June	1	5	–
July	2	–	–
August	–	–	–
September	3	2	–
October	4	–	1
November	3	2	7
December	2	2	10
Total	30	20	42

This more even distribution of the rainfall at that time seems to have permitted the settlement of places a good deal farther inland than the present narrow strip along the coast. Such former prosperity is also attested by the location of the large Christian town of Abumina and the church of Qasr el-Qitaji, both of which were situated well inland where there was no permanent water supply (Murray 1951; Brooks 1949).

Three great catastrophes hit Egypt during the sixth and early seventh centuries A.D. The great plague of 542 to 600 A.D. was the first. The second was the low water of the Nile during the period. The third was the submergence of the northern and northeastern part of the delta under the sea (see Part I, p. 76). Under these circumstances the Egyptian population declined to about 2.5 million and remained low for a long period (Russell 1966). We shall discuss the effect of these catastrophes in greater detail in Part III of this book.

6.3. Nile Fluctuations in Medieval Egypt (The Roda Nilometer)

As previously mentioned the levels of the rise of the water of the Nile were measured regularly from the earliest of times. These measurements were recorded in registers which were considered among the state's most important documents. In medieval Egypt the measurements were made mainly at the Roda Nilometer which was built at the southern tip of the Roda Island (Old Cairo) in the year 715 A.D., some 75 years after the Arab conquest of Egypt, to replace the various nilometers in the Cairo area and in particular the old Memphis nilometer or "house of inundation" that had been standing in that place since antiquity. A survey of these nilometers is given in Popper (1951). The Roda Nilometer furnished the official readings of the level of the Nile until the beginning of the twentieth century. It now stands as a museum and is probably the oldest Islamic monument in Egypt (Ghaleb 1951). Although most of the documents have been lost, enough have survived in the compilations of historians of the fourteenth and fifteenth centuries so that today we have an almost complete register of the levels of the Nile since shortly before the Arab conquest. No other river surpasses this long record.

The Roda Nilometer was built during the reign of the Umayyid Caliph Abdel Malek ibn Marawan. It was almost rebuilt during the reign of Caliph el-Mutawakil in the year 861 A.D. after it had been swept away by water. It is uncertain from the accounts whether the second building represented an entirely new reconstruction or only some changes in the first. In later times the nilometer of 715 A.D. was known as "the old" and that of 861 A.D. as "the new"; in all probability the nilometer of 715 was in its main features the same as that of 861. Abu el-Raddad of el-Basra was appointed guardian of the "new" nilometer. The post remained for close to one thousand years in the family of Abu el-Raddad until at least the visit of Stanley Lane-Poole in 1830 A.D., who mentions in his book *Manners and Customs of Modern Egyptians* that he had met a member of the Abu el-Raddad family at the nilometer.

The nilometer (Fig. 2.26) is a well which is connected to the Nile by three tunnels the southern of which is at the level of the floor of the well (8.15 meters above sea level) while the other two are to the east, one lying above the other. The lower of the two is 1.6 meters above the floor of the well; the upper is in the shape of a vault and lies 2.8 meters above the floor of the well. Inside the well stands an octagonal pillar of marble placed on a pedestal. The scale of the nilometer is inscribed on the pillar. It was changed twice during the course of time (Fig. 2.27). The unit of measurement in all three scales was the cubit which was subdivided into fingers.

The cubits in the oldest scale of the nilometer were subdivided into 28 fingers from cubit I to XII and into 24 fingers from cubit XIII to XXI. Since the fingers of both parts of the scale were equal (1 finger = 1.925 centimeters), the cubit in the lower part measured 53.9 centimeters and that in the upper part 46.2 centimeters. The zero point of the scale was fixed at the level of the floor of the well. This made the height of cubit XVI 8.3 meters above the floor of the well (or 16.4 meters above sea level). At the time of the construction of the nilometer the level of cubit XVI was also the effective level of the flood at which the dikes were broken, the water allowed in the fields and the agricultural season initiated.

Five years after the Turkish invasion in 1517 A.D. a new scale was set up in which the zero point was elevated by 1.62 meters above the floor of the well and the cubits from IX to XXVII were reduced to 36.1 centimeters each.

In 1861, during the reign of Khedive Ismail, Engineer Mahmoud Saleh el-Falaki repaired the gauge and replaced the old scale by a new one in which the zero point was fixed at 66 centimeters above the floor of the well and the elevation of each cubit in meters above sea level was engraved opposite its mark. Each cubit in the new scale measured 54.1 centimeters except cubits XVI to XXII which measured 27.1 centimeters each. This was done to adjust the Cairo readings with those at Aswan; for when the level of 16 cubits was reached in Aswan, the basins of upper Egypt were inundated; this reduced the level of the water in Cairo to one half.

One of the important reasons for changing the scale and the zero point of the nilometer from time to time was to adjust it to the new level of the river bed and its flood plain which kept rising as a result of the yearly accumulation of silt carried by the river during its flood time. We have already dealt with this phenomenon in some detail in Part I of this book. From the earliest of times the Egyptians had found out that the river could best inundate the land when it rose some 6.5 meters above the level of low water (or minimum level). This level increased with time as

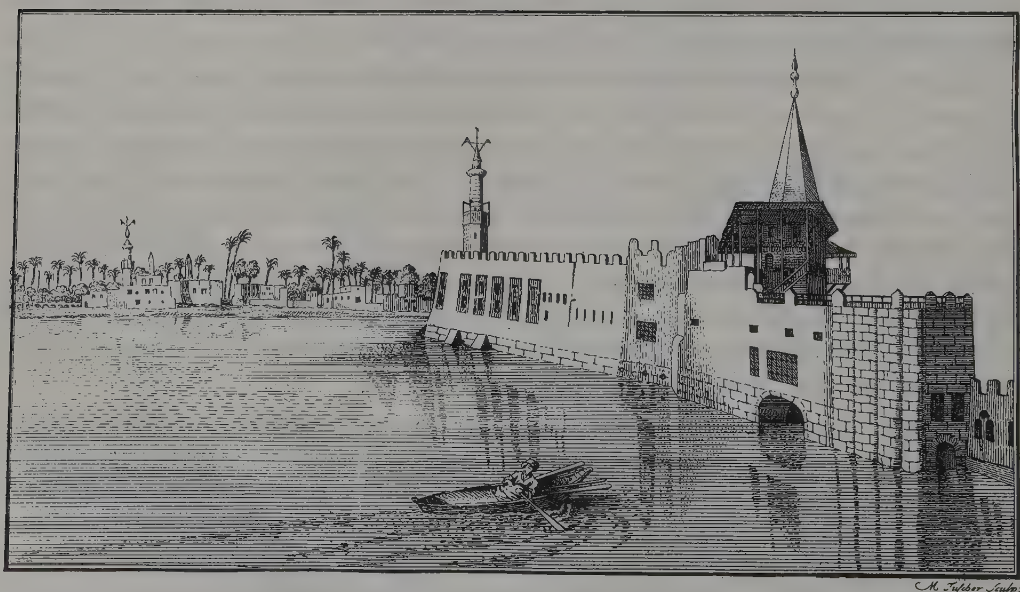

Fig. 2.26a. Roda Nilometer in 1757 (after F.L. Norden 1757).

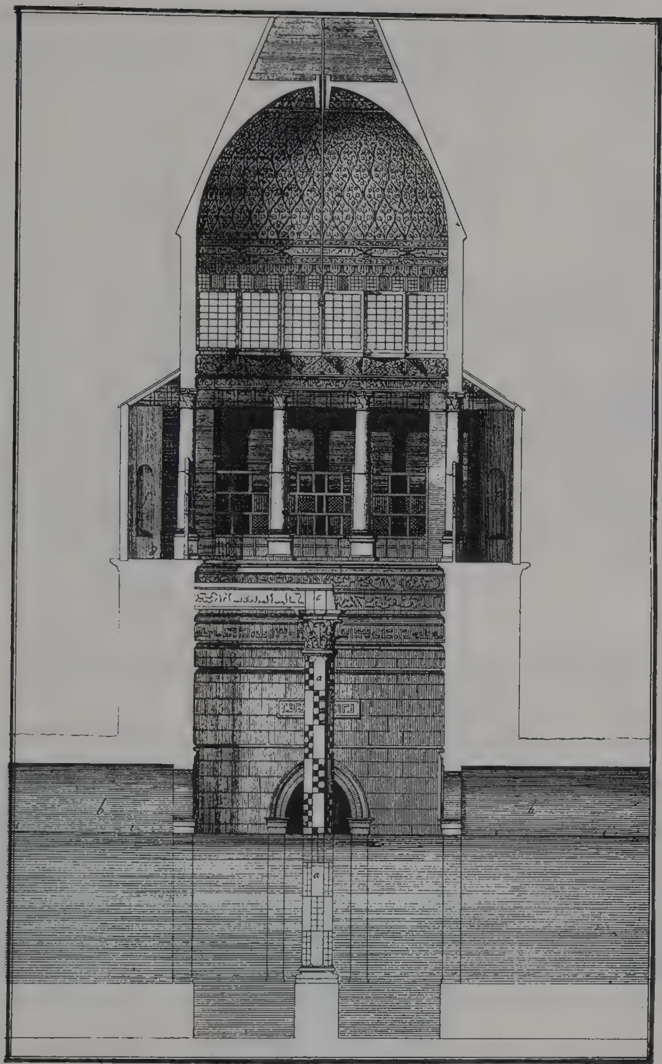

Fig. 2.26b. The scale of the Roda Nilometer in 1757 (after F.L. Norden 1757).

the land rose. When the Roda Nilometer was built the "effective" level was at the level of cubit 16 which lay some 8.3 meters above the floor of the well. At that date the average low water level was 1.92 meters above the floor of the well. Nine-hundred years later the bed of the Nile and the land of Egypt were higher by about 1.5 meters, with the result that the level of cubit 16 became no longer an effective level. Consequently the scale of the nilometer needed to be recalibrated and adjusted to the rise of the land. This happened five years after the entry of the Turks in Egypt when Ottoman measurements were introduced and the zero point was elevated above the floor of the well by an amount equal to that to which the land had risen. The effective level on the new scale was the level of cubit 18 which lay 10.1 meters above the floor of the well. When the third scale was introduced in 1861 the effective level became the level of cubit 22 which lay 10.9 meters above the floor of the well.

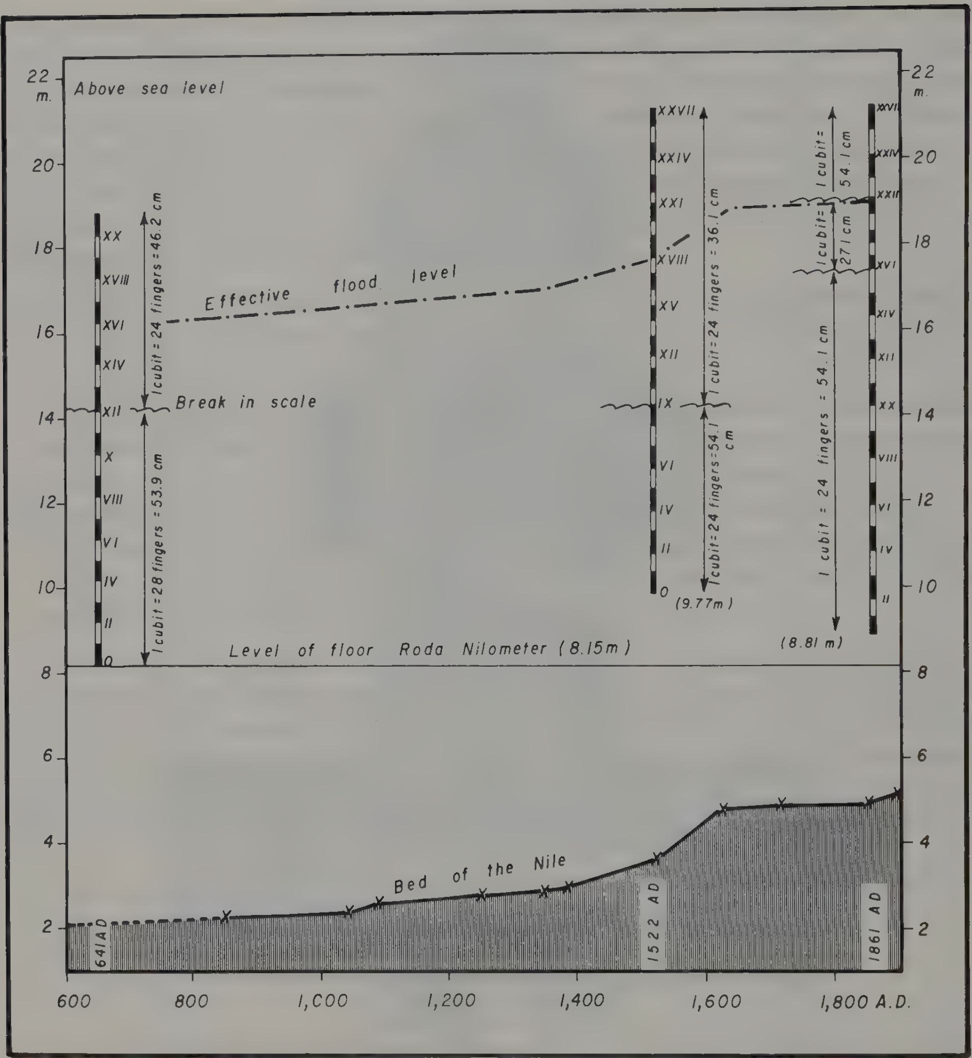

Fig. 2.27. Upper, the three scales of the Roda Nilometer used in 641, 1522 and 1861 A.D., the elevation of their zero levels in meters above floor of gauge and above sea level; Lower, the bed of the Nile as it rose over time.

The following table gives the average levels of the bed of the Nile, the low water, the effective flood level at the years when the scales of the nilometer were first introduced. All the figures are from Popper (1951) and are in meters above the floor of the well, which lies 8.15 meters above sea level.

It is to be noted that the celebration of the plenitude of the river continued to take place when the height of the flood reached the level of cubit 16 on the scale, although this was not the most effective level for the beginning of the agricultural year. It was lower by 70 centimeters in the case of the second scale and by 160 centimeters in the case of the last scale. Even in the case of the

Year (A.D.)	bed of river	low water	effective level	cubit on scale
641	-5.8	1.9	+8.3	16
1522	-4.2	3.4	+10.1	18
1861	-3.1	4.4	+10.8	22

first scale, which remained unchanged for close to 1000 years, the level of cubit 16 did not represent the effective level for most of the period; the bed of the river rose during that time by more than 1.5 meters. It is likely that the reason behind the early announcement of the agricultural season was to allow the government to start assessing the land tax, which was due only when that level was reached. This tradition went back to the time of the Arab conquest, when in the treaty made with the Copts, it was stipulated that if the Nile reached less than its "customary" height the tax would be proportionately reduced. The history of land tax in Egypt is given in Popper (1951: 73–82).

6.3.1. Sources of the records of the Roda Nilometer

The annual minimum and maximum levels of the Nile as recorded at the Roda and previous nilometers in the Cairo area from the year 622 to the first part of the twentieth century were assembled by a number of authors. The oldest of the manuscripts compiling the levels of the earlier years is that of Abdalla Ibn Iybak who, around the year 1335, recorded in his manuscripts *Durar el-Tigan* and *Kanz el-Durar* the minima and maxima for the years 622–1241, none for the years 1242–1294 and sporadic maxima for the years 1295–1335. The most complete and dependable record of the earlier years are given in the works of the fifteenth century authors Gamal el-Din Abu el-Mahasin Ibn Taghri Birdi and Ahmed Ibn el-Higazi who supplied parallel though not always identical figures for the maxima and minima of the years 641–1469. In his two manuscripts *Al-Nigum Al-Zahira* and *Hawadith Al-Dehour* Ibn Taghri Birdi gives records for the years 641–1467 and the years 1441–1469. Ibn el-Higazi gives in his manuscript *Nail el-Raid min el-Nil el-Zaid* records for the years 622–1469.

After the year 1469 and until the beginning of the seventeenth century the records become sporadic and are gleaned from the works of many authors. Chief among these is Ibn Iyas (1467–1524) who gives in his manuscripts *Bada'i el-Zuhur and Nushq al-Azhar* the levels of nineteen years (1504–1522).

The maxima and minima of the years 1586–1873 are compiled in the well known history of Ali Pasha Mubarak *al-Khutat al-Tawfiquia* (20 volumes, Cairo Government Press, 1899). The records of the years 1586–1735 (with the exception of the years 1632–1657 which are missing) were extracted from the documents of the guardian of the nilometer, while those from the years 1736–1800 were copied from Le Pere, the French Expedition savant. The nineteenth century records (with the exception of the years 1801–1824 which are missing) were compiled from the state documents. Mahmoud Saleh el-Falaki gives a listing of the years 1825–1873. After 1873 Egypt's Ministry of Public Works became responsible for the records of the Nile which has been published regularly in supplements of *The Nile Basin* compendium since the early years of the twentieth century.

It must be admitted that the degree of authenticity of the records is not great. This is especially true for the records of the earlier years which are derived from texts written some 700 years after the occurrence of the events, and copied from documents that are unknown and have since been lost. It is no wonder that the task of verifying these texts was laborious and not without controversy. The following works include useful compilations of the maxima and minima of the Nile from the earliest years of the Roda Nilometer: Ali Mubarak (1899), Amin Sami (1915 et seq.), Tousson (1925) and Popper (1951). Popper found Ibn Taghri Birdi's manuscript to be the most complete and reliable of the old texts. He edited and published the manuscript in the University of California Publications on Semitic Philology (1909–1939). Popper also adjusted the records to take account of the changes in the scales used, the rise of the bed of the Nile, the differences in lunar and solar calendars and the shifting of the course of the Nile. He also converted the records from cubits to meters.

The effect of the rise of the bed of the Nile on the validity and comparability of the records has already been discussed. Another difficulty with the old records is that they were registered against lunar years inspite of the fact that the rise of the Nile is a solar phenomenon. The lunar year is shorter than the solar year; it completes its cycle in about 10 days and 10 hours shorter than the solar year. Consequently there are about 33 solar years (or floods) for every 34 lunar years. Unfortunately the old authors did not take this fact into consideration. Amin Sami mentions in his *Taqwim* that in compiling the lists of the flood levels of the lunar years 20–856 Hegira he found that there were 24 superfluous levels. In times of good governments this discrepancy was handled through an edict that "skipped" one lunar year every 34 years (Arabic Izdelaf) so that the lunar and solar (or tax) years would coincide. Unfortunately, this correction was not always implemented and the data, therefore, include some that are superfluous. Popper and Amin Sami compared the data of the numerous authors, noted those that were duplicated and compiled corrected tables.(2)

Although officially the lunar calendar was introduced into Egypt after the Arab conquest, the Coptic solar calendar continued to be used for agricultural and fiscal purposes. The fiscal land–tax year was based on agriculture; the land tax was due after the harvest, and the completion of payment was required before the next seedtime. In Egypt the fiscal year coincided with the Coptic year, the beginning of which (Tut 1) falls on September 8 or 9. This year consists of 12 months of 30 days each and an added period, called Nas'i, of 5 days in three successive years and 6 days in the fourth year. It is a rectified version of the ancient Egyptian calendar. It started with the accession of Emperor Diocletian in 284 A.D., a year which has since been termed the year of the Martyrs in memory of those who were killed for their Christian faith during the reign of this emperor. In 1839 Mohamed Ali decreed that the Coptic calendar, which had been in use for the collection of taxes be used also for government accounting and budgeting. In 1875 Khedive Ismail replaced it with the Gregorian calendar.

A further factor that throws doubt on the accuracy of the records of the Nile is the impact that the shifting of the bed of the river must have had on the readings; the same volume of water would register differently in response to variations in the width and cross section of the river

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(2)The year 1203 Hegira was the last year known to have been dropped by an edict of skipping to adjust with the tax year 1788 A.D., according to the famous late eighteenth–early nineteenth century historian el-Gabarty. See Mohamed Kamal el-Sayed (1986).

which we know to have changed drastically since the time of the building of the nilometer (Part I, p. 63). The same quantity of water passing through the nilometer would register a higher level when the river channel is narrower, and vice versa.

6.3.2. The records

Inspite of all these reservations the adjusted records form an extremely valuable series that could help unravel the regimen of the river and the history of its fluctuations. Figures 2.28 and 2.29 plot the values of the minima and maxima of the river from the year 640 to 1870.

Several attempts have been made to find periodicity in these records. The list is long and includes Aguado (1987); Brooks (1927); Evans (1990); Fraedrich & Bantzer (1991); Jarvis (1935); Hameed (1984); Hassan (1981); Hassan & Stucki (1987); Hurst (1951); Hurst, Black & Smaika (1965) and Riehl & Meitin (1979). If we look at the Nile levels across the 1300 years of records from the Roda Nilometer we find that these years constitute one cycle of low Niles with small fluctuations; it is similar to the large cycles we noted in the early history of the Neonile. According to Hurst (1951) the records show little departure from the mean; 70 percent of the readings are within one half meter of the mean, and less than 2 percent are within 1.5 to 2 meters of the mean. The year 1913 was the lowest ever; it was 2.36 meters below the mean. It is followed by the year 967 which was 1.89 meters below the mean. Because of the smallness of the average standard of deviation of the flood levels, the periodic effects are relatively small.

However, the Nile flood levels show some oscillation. They follow a normal Gaussian probability curve where years of low flow, like those of high flow, follow one another and tend to be grouped together. The principal feature of the series is the existence of 50 to 100 year periods when, on the whole, the floods were alternately high and low. The apparent persistence of long periods of high and low flow has been termed the Hurst phenomenon, in recognition of H. E. Hurst the pioneer hydrologist who devoted all his working years to the understanding of the hydrology of the Nile. This phenomenon is significant in working out the long term storage capacity of reservoirs to guarantee a given draft. It was used in the case of the Aswan High Dam to determine the storage requirements needed to provide full regulation of the Nile and to remove the vagaries of droughts and high floods.

Inspite of the fact that all authors who worked out the time series of the Roda Nilometer levels are in agreement that these records show systematic periodicities, they differ in the frequency of these periods. They used different signals to divide the cycle into periods of different durations. According to Hameed (1984) the minima series of the Nile show a signal every 77 years (presumably indicating the influence of variation in solar activity) and another significant oscillation every 18 years (possibly associated with the nodal lunar tide).

Most authors are also in agreement that the minima series show more enhanced short period fluctuations than the maxima series which display reduced persistence of the fluctuations (Fraedrich 1991). Most authors who worked out the periodicities of the Nile levels, therefore, based their analyses on the minima. This is unfortunate since the minima reflect the oscillations of the level of water in the low season, which played a minor role in the life and prosperity of Egypt until the beginning of the nineteenth century; Egypt until then depended solely on winter agriculture and the summer waters of the Ethiopian Highlands which swelled the height of the river above the effective level. The periods suggested by these authors, therefore, do not match with the famine chronologies of Egypt. The periods discussed in the following paragraphs, on

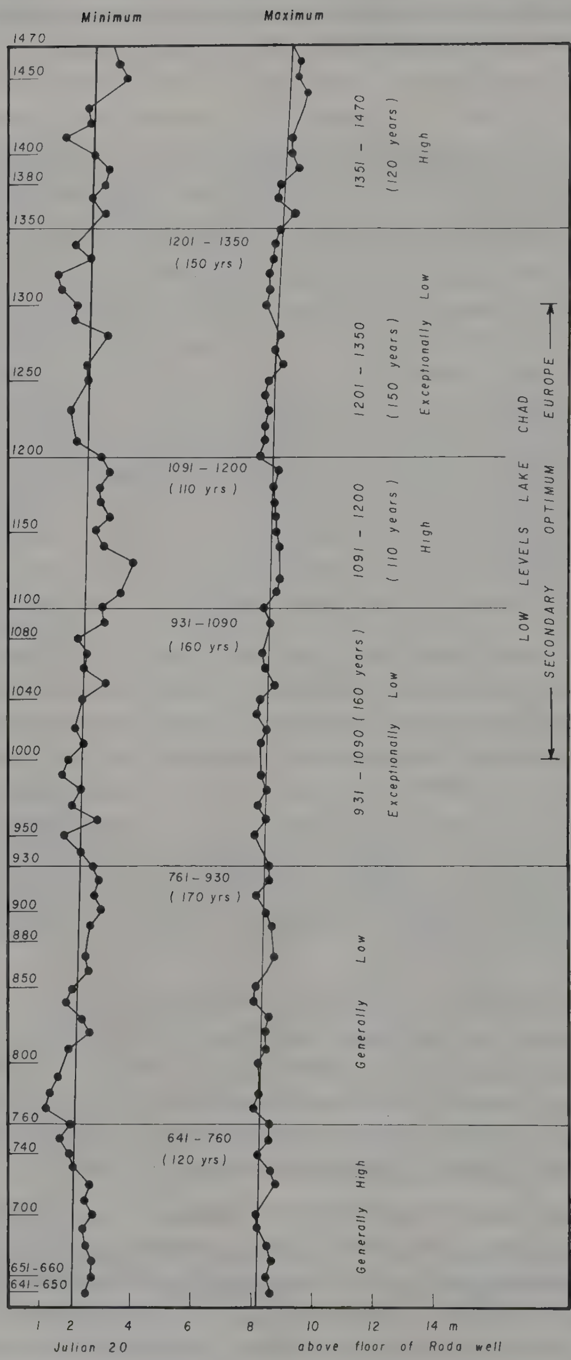

Fig. 2.28. Maxima and minima (plotted as 10-year averages) as registered on the Roda Nilometer 641–1470 A.D. (data from Popper 1951).

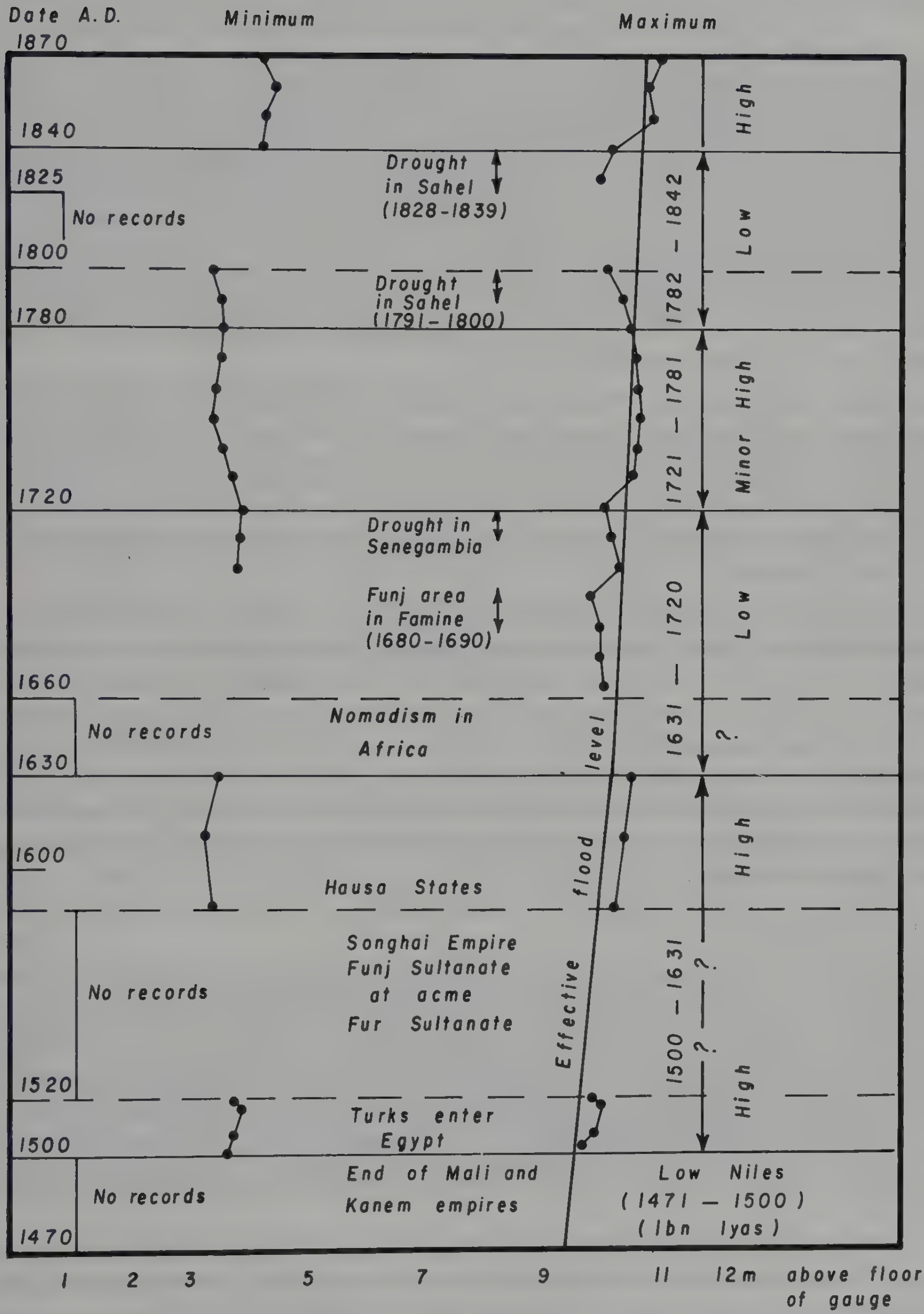

Fig. 2.29. Maxima and minima (plotted as 10-year averages) as registered on the Roda Nilometer 1741–1870 A.D. (data from Popper 1951).

the other hand, are a match between those which the levels indicate and those the chronologies allude to.

6.3.2.1. Period 640–930 A.D.

The period from 640 to 930 A.D. was characterized by having ample flood levels, although the first 120 years of this period had higher floods than the following 170 years. The 290 year period had only 50 years of lower than usual floods. The average maximum level of the entire period was 8.9 meters above the floor of the well, some 60 centimeters higher than the effective level at the beginning of the period. Inspite of the great destruction, in particular of the infrastructure and the irrigation system of the delta region which Egypt witnessed twice during this period (as a result of the usurpation of power by the Umayyids in 685 and by the Abbassids some 65 years later in 750 A.D.), there is little mention in the writings of the time of great calamities resulting from the failure of the Nile.

During the earlier years two of the lowest floods on record occurred in the years 650 and 694; the discharge fell from a yearly average of slightly over 90 billion cubic meters to barely 66 billion cubic meters in each of the two years. A period of a slightly lower Nile with below average yearly discharge occurred between 688 and 703 when the flows averaged slightly less than 86 billion cubic meters. In 10 years of this latter period (690–699) the average fell to below 83 billion cubic meters.

During the period which extended from 760 to 930 the water reaching Egypt from the Ethiopian Highlands seems to have been less than usual, for inspite of the increase in the level of the minimum, which became quite noticeable after the year 820, the maximum level did not increase proportionately. During these years the average maximum did not exceed 9 meters and the rise of the flood waters above the low water level was 6.4 meters. The average discharge was about 89 billion cubic meters. The lowest years were the years 841 and 903 when the discharge fell to 69 and 64 billion cubic meters respectively. The years 800–809, 832–858 and 945–977 had lower than average discharges, some 2 to 3 billion cubic meters less than the average discharge for the period.

6.3.2.2. Period 931–1090 A.D.

Nile failures were reported during most of this 160 year period. The average of the maximum levels was 8.8 meters above the floor of the well, a height which did not allow the flood waters to override all the basin lands in most of the years; the effective level rose to 8.8 meters at the beginning of the period and to 9.1 meters at the end of the period. An interesting feature of the maximum levels is that they were constant throughout the period, showing no great fluctuations or deviation from the mean (Riehl & Meitin 1979). The minima, on the other hand, showed more fluctuations but were lower on the whole than those of the earlier period, when they surged after the year 820.

The low level of the maxima of the Nile during this period may have been due to the lower minima of the period rather than to a lower contribution from the Ethiopian Highlands (Fig. 2.28).

The lowest year in this period (and the second lowest in the entire record of the Nile) was the year 967 which had a discharge of about 54 billion cubic meters. The years 945–977 had a lower than average discharge (83 billion cubic meters). The low Niles of this epsiode were

exceptionally destructive of the economy as several successive failures of the Nile left the larger part of the land of Egypt uncultivated. Raids by tribes from north Africa, driven by the droughts of the period, finally led to the Fatimid takeover of Egypt in the year 969 A.D.

Eighty years after its conquest at the hands of the Fatimids, Egypt was struck by another episode of low Niles; the years between 1052 and 1090 were the lowest ever. Out of the 40 floods of these years, 28 were low and many came in succession and without respite. This episode is known in the annals of Egyptian history as the years of *el-Shidda* Al-Mustansiriya, after the Fatimid Caliph Al-Mustansir who ruled Egypt at the time. Eyewitness accounts of the period describe food shortages, excessive inflation, mass immigration, decline of the arts and crafts, starvation, death from hunger, spread of disease and plague and even cannibalism. The period also saw the Egyptian population reduced from 2.4 million at the beginning of the tenth century to about 1.5 million at the end of that century.

An eyewitness account of the year 1068 A.D. reads:

> "In that year inflation reached levels unheard of since the days of Joseph (God bless him). The drought and plague were so severe for seven consecutive years that people ate cadavars. Beasts were wiped out. The dog sold for five dinars and the cat for three. Only three horses of a large number remained to the Khalif. One day the Vizier dismounted from his mule ...when three men attacked the mule, killed it and ate it. They were taken and crucified. No sooner had they died than they were fallen upon by the mob and devoured until nothing was left but their bones. A man was killed when it was rumored that he had killed young boys and women and sold their flesh for meat. The one egg cost a dinar, an ardeb of wheat a hundred dinars and even at that price was not available. It was narrated that a woman in Cairo offered a handful of jewels in exchange for a handful of wheat, and yet no one paid any attention to her."

6.3.2.3. Period 1090–1195 A.D.

This period was characterized by normal and good floods. The minimum level rose to its highest level ever and averaged 3.7 meters above the floor of the well. The maximum level also rose to an average of 10.5 meters above the floor of the well, one meter higher than the effective flood level, which rose to 9.5 meters at the end of the period. The discharge of the river was never less than 89 billion cubic meters except in the years 1144–1149 when it averaged 86 billion cubic meters.

The period was contemporaneous with the period of climatic optimum of Europe which was characterized by warmer temperatures and frequent droughts in Europe and, according to one scenario (Flohn & Nicholson 1980), by a more humid Sahara and wetter Africa to bring about the high minimum levels of this period. The period of climatic optimum affected Europe and North America during the eleventh to the thirteenth centuries when summer temperatures increased, making possible the settlement of Greenland and other hostile areas today. The increase of temperature may have been higher by less than one degree celsius than today.

6.3.2.4. Period 1196–1350 A.D.

This period of lower Niles was characterized by a decrease in the minimum levels. The average maximum level was reduced to 9.7 meters above the floor of the well. In the meantime the effective level rose to 9.8 meters at the end of the period. There were no great famines except during the opening years of the thirteenth century which were tragic and disastrous; they witnessed the end of the Fatimid Dynasty. Perhaps the worst year of this epsiode was the year 1200 when the discharge of the river fell to 58 billion cubic meters.

6.3.2.5. Period 1351–1467 A.D.

This period was characterized by very high floods. The average of the maximum level was 10.9 meters above the floor of the well while that of the minimum level was 2.9 meters. The height of the water during flood time exceeded any other period causing damage especially in years when the high waters continued after the sowing season.

The floods were exceptionally high in the years 1359–1360 when "people went out to the desert beseeching God to reduce the level of the Nile". According to Al-Maqrizi the Nile at that time rose to 24 cubits so that "the people were afraid of being overflooded"; it persisted at this level until late in October, past the season of sowing. There was a respite of 16 years when yet another period of high floods hit Egypt during the twenty-year period 1376–1395. During that episode there were 7 years of exceptionally high floods. High floods were also recorded for the years 1409 and 1422.

Several years of low Nile alternated with these years of high flood causing famines such as those reported in the years 1336, 1374, 1394 and 1403. In addition to these unusual events caused by the extreme variability of the Nile, this period was also marked by the outbreak of the great plague (1348–1420) which according to Al-Maqrizi wiped out half the population in the years 1403 and 1404 alone. The high floods, famines and the plague reduced the population of Egypt from about 4 million around 1300 to 3 million at the end of the fifteenth century (Russell 1966).

There is evidence that during this period of relatively higher floods the Sahara flourished and strong states and empires developed (Fig. 2.30). The greatest sub-Saharan State of which there is any authentic record was centered at Mali which extended to include the Niger bend; its splendor at its height in the fourteenth century was described by Ibn Khaldun (ca. 1406 A.D.). Ibn Battuta concluded his well-known travels in the Islamic world with a visit to it before returning to his native Morocco in 1353 A.D. About the same time the northerly Hausa city states developed at Kano. They were unknown to Arab travellers until the late fifteenth century when a trans-Saharan trade route developed. The Kanem state, which was centered around Lake Chad, expanded during the drought of the early years of the thirteenth century and spread over a great part of the Sahara. According to Ibn Khaldun, this state extended during the fourteenth century from Lake Chad to Tibesti and Fezzan, and developed trade and diplomatic relations with the Hafsids in Tunisia.

6.3.2.6. Period 1468–1510 A.D.

The scattered records of the Nile during the following 42 year period between 1468 and 1510, as given by Ibn Iyas (1467–1524), indicate that the period was one of lower Niles. There were low Niles during the years 1468–1475, 1484–1487, 1502–1507 and 1509 A.D. The Sahara also seems to have witnessed a drought; the Mali and the Kanem Empires disintegrated and the Tibesti became isolated forming the Borno State.

6.3.2.7. Period 1511–1630 A.D.

From 1510 to 1630 there is again a scarcity of data, but the few records indicate a normal Nile. The beginning of the period saw the invasion of Egypt by the Ottoman Turks who found the country in disarray; the loss of the revenue from the transit trade to India after the discovery of the Cape of Good Hope by the Portuguese had severely damaged the economy. Historical documents point to a more hospitable Sahara and to the expansion of the African States deep

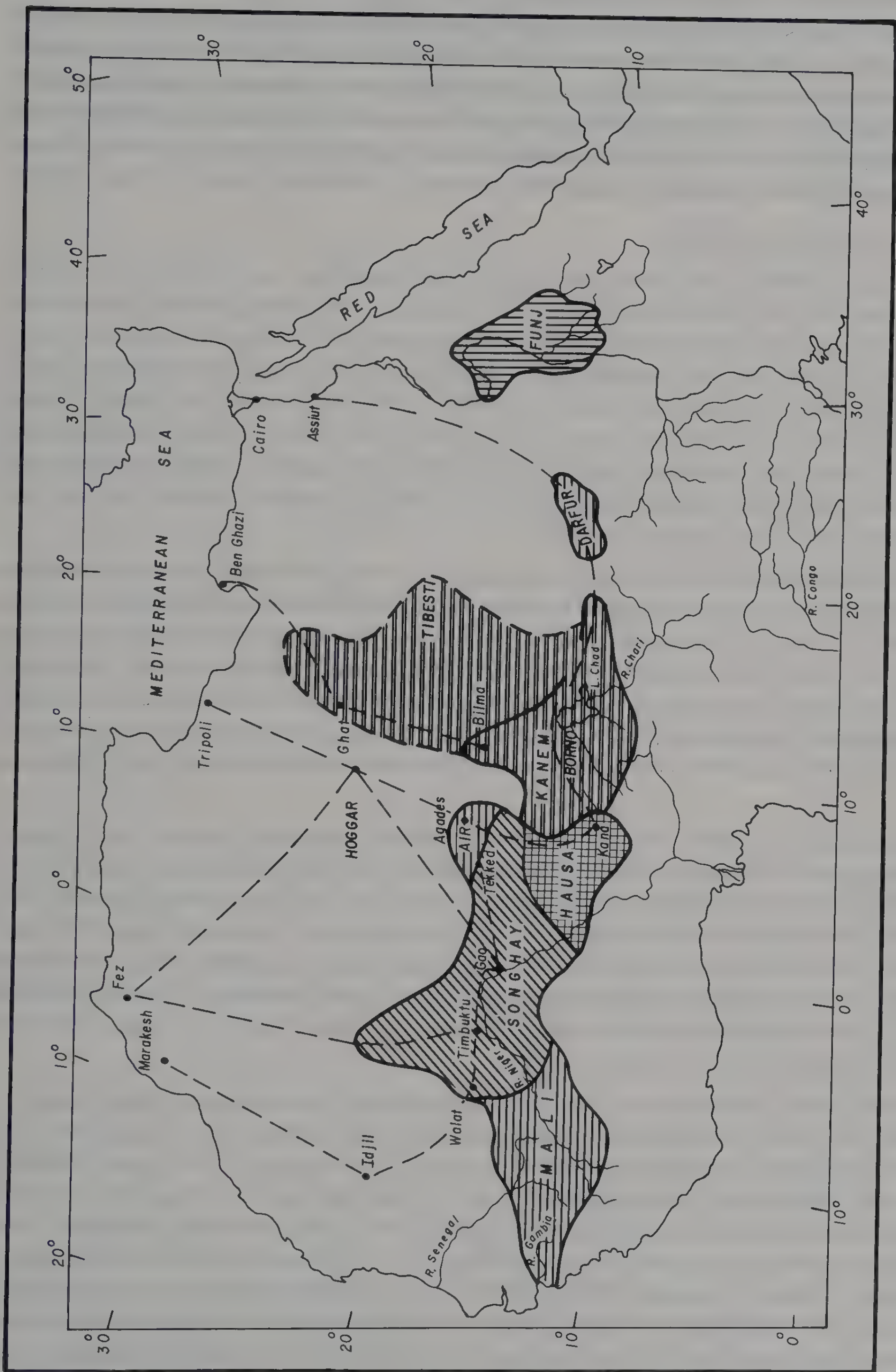

Fig. 2.30. The Saharan states and empires in the sixteenth century.

into it during the sixteenth century (Fig. 2.30). The Songhay Empire, which started along the Niger River, expanded northward up to Taghaza and became a power to reckon with until its downfall at the hands of the Moroccans in 1591. A number of new states emerged or began to make their impact felt on the edge of the northern Sahara: the Air Sultanate around Agades, the Darfur Sultanate at Gebel Marra and the numerous Hausa states. In the Sudan the Funj Sultanate was at its peak. The Funj, whose origin remains obscure, settled in Sennar on the Blue Nile and rapidly extended their domination northward in Nubia.

6.3.2.8. Period 1631–1840 A.D.

With the exception of a 60-year period (1721–1780) when there was a minor increase in the level of the Nile, the 210 years extending from 1631 to 1840 were generally low; and the Sahelian region saw frequent droughts, the disintegration of the empires and the revival of nomadism. Among the best documented of the droughts is that of the years 1681–1687 (Nicholson 1980). It seems to have affected the entire east–west extent of the Sahel; reference is made to it in the chronicles and reports from the Chad, Darfur and Funj areas. Another lengthy period of famine and drought occurred ca. 1710–1720 in Senegambia. There were two other episodes of lower Niles which coincided with two Sahelian droughts reported from the Chad area in the years 1791–1800 and 1828–1839.

The mid-eighteenth century was an unusual period. It was characterized by severe Sahelian droughts which were not accompanied by lesser rainfall on the Ethiopian Highlands. Between the years 1730 and 1750 the Sahel zone of central and West Africa was ravaged by a severe drought supposedly killing half the population of Timbuctu and other parts of the Niger bend (Nicholson 1980). This period of famine and drought, perhaps the most severe ever recorded, was reported in Senegambia, Mauritania, Mali, Upper Volta, Dahomey, Ghana, Nigeria and Chad. In the Ethiopian Highlands, however, there were abnormally high rains and the Nile was high.

It is interesting to note that this period of droughts coincided with the Little Ice Age of Europe when the glaciers advanced between 1600 and 1850. The Little Ice Age is one of the best recognised short-term fluctuations of the recent climate. It is globally recorded between 1550 and 1850. Records from Europe show that it was a much wetter and colder period. Iceland, which is now locked in sea ice only one to three weeks a year, was then icebound five or six months a year. In London the Thames River froze every winter, something it did not do before or after. In North America, the east coast was colder than today but the west may have been warmer. In North Africa the weather was dry.

The early years of the nineteenth century were exceptional years in that they were interrupted frequently by years of high floods; the years 1800, 1809 and the three successive years 1818–-1820 had very high floods. A vivid description of the flood of 1818 is given in Belzoni (1820) who witnessed the flood during his travels in Upper Egypt when on September 16, 1818 "the Nile rose three feet and a half above the highest mark left by the former inundation, with uncommon rapidity, and carried off several villages and some hundreds of their inhabitants". El-Gabarty's chronicles mention in the events of the year 1233 Hegira (1818 A.D.) that the Nile rose to such an extraordinary height at Cairo that the Island of Roda was completely submerged, boats were able to sail over it, many villages were destroyed, a considerable number of the inhabitants and their animals were drowned and there was great lamentation among the fellahin

over their summer crops. El-Gabarty goes on to mention in the chronicles of the following year that there was a still more disastrous flood, the inundation not only reached greater heights than in the previous year sweeping with much violence over the highest banks, destroying all the field crops, including the cotton as well as the fruit trees in the gardens, but also lasted for an abnormally long period. At first there was a slight fall which was followed by a renewed rise to still higher levels after Holy Cross Day (September 27), the water not subsiding until the Coptic month of Hathor (November), long after the season of cultivation had passed.

7

CONCLUDING REMARKS

The discovery of the sources of the Nile less than 150 years ago made posible the systematic monitoring of the flow of the river from its sources to the Mediterranean; it also made possible the scientific study of its hydrology. Prior to this the sources of the river and its rhythm were wrapped in mystery. In addition to the pioneering works of the earlier hydrologists there are at present a large number of studies on the hydrology of the river that are carried out in the universities and the different research institutes of the Egyptian Ministry of Public Works and Water Resources. Some of the more recent results can be seen in the Water Master Plan technical reports, in the research reports of the Cairo University/MIT Technological Planning Program and in the Egypt–Sudan Technical Commission Reports.

The water of the present-day Nile comes from two sources, the Equatorial Plateau and the Ethiopian Highlands, both of which receive large quantities of rain. Only a fraction of that rain is channeled through the river to its downstream part and to the sea; a large part is lost through seepage, evapotranspiration and overbank flows to the swampy lands that fringe the basin in many parts and especially in its equatorial stretch. It is difficult at the present state of knowledge to quantify the water balance of the total basin of the Nile. Inspite of the efforts of the pioneer hydrologists, the different government departments and the UNDP–WMO project (Hydromet) the meteorological data of large parts of the basin are insufficient. Large quantities of water are lost in both the Bahr el-Ghazal and the Sobat basins; the water that exits from them is a fraction of what they receive. In the case of the Sudd basin alone, close to 50 percent of the water is lost as it passes through the swamps, and considerable quantities are lost even before the water reaches the Sudd itself.

In addition to these losses, the carrying capacity of the main rivers which transmit the waters of the Nile to its downstream part and the sea are limited. The cross sections of the White Nile, the downstream part of the Blue Nile and the Main Nile to the north of Khartoum are such that they do not allow but a limited quantity of water to pass, spilling over the banks whatever additional water reaches them. It would seem that the present-day regimen of the river would not carry beyond Atbara more than 150 billion cubic meters of waters per year. During the earlier phases of the Holocene (Nabtian) Wet Phase the modern river carried larger quantities of water. Since there seem to have been no significant changes in the topography or the cross sections of the rivers which today transmit the waters of the Equatorial Plateau and the Ethiopian Highlands, it would seem that the additional water of that period must have come from new catchment areas that the river had tapped in northern Sudan, Nubia and southern Egypt. Such physical changes in the topography of the river and its cross section may have been effective

in the case of the older rivers. The changes probably made the conduit of large amounts of water from the Ethiopian sources of the river possible in the case of the old middle Pleistocene river which carried extremely large amounts of water.

We have already mentioned that the modern river came into being as a result of the interconnection of several independent basins and their integration into one river during the last wet phase which affected Africa after the retreat of the ice of the last glacial some 10,800 years ago. The wet phase brought enough water for the basins to overflow their banks and join other basins, thus forming a flowing river of multiple sources and a large catchment area. The wet phase was the result of the latitudinal shift of the intensified monsoonal rain front to the north. As long as the wet phase lasted the river's flow was considerably larger than today. Since the end of the wet phase and the southward shift of the monsoonal rain front some 4400 years ago, the flow of the river has tended to decline steadily and to show great fluctuations.

Two periods, therefore, can be distinguished; an earlier period which lasted about 6600 years (ca. 9000–2400 B.C.) when the flow of the river was large, and a later period which lasted about 4400 years (2400 B.C.–present) when the flow of the river was small. River flow data from the earlier period permit the recognition of only the large cycles of fluctuations of the river during that time. The two earlier cycles of high river flow (9000–8000 B.C. and 7500–6000 B.C.) were exceptionally high and the discharge of the river was probably in the range of 250 to more than 300 billion cubic meters per year. The rain front of the Holocene Wet Phase was at its maximum extent to the north, and the catchment area of the river was large. After a spell of 800 years of a relatively drier period (6000–5200 B.C.) the flow of the river became smaller as a result of the retreat of the rain front and the decline in the amount of rain. The discharge of the river during the high cycles of this sub-period (5200–3900 B.C. and 3100–2400 B.C.) was in the range of 200 billion cubic meters per year. Although the cycles in which the river was high were considerably longer than the cycles in which the river was low, these latter had the greatest impact on human history; they instigated mass migrations, cultural contact and frequently conflict. The low cycle between 6000 and 5200 B.C. was of especial import. It was the result of a dry spell that interrupted the Holocene Wet Phase. It did not only mark the beginning of a new regimen for the river, in which the flows became smaller, but it also instigated the migration and settlement of the desert people in the Nile Valley, a migration that was destined to have a tremendous impact on the future of the river. Of interest also is the period of high flood levels that was concurrent with the Old Kingdom of Egypt and which was the last of the cycles of the early period. It ended with a bang; a series of low Niles hit Egypt at the end of that cycle causing Egypt to disintegrate into anarchy and a dark age.

After the end of the wet phase at about 2400 B.C. the discharge of the river became generally small and tended to decline steadily. The discharge of the river decreased from above 100 billion cubic meters a year at the beginning of the period to about 90 billion cubic meters after the mid years of the first millenium A.D. An analysis of the discharge data for this latter period shows that exceptionally high floods occurred during a 110 year period in the fourteenth and fifteenth centuries A.D., while exceptionally low floods occurred in the tenth and eleventh centuries A.D. and also in the twentieth century. This latter century represents, in fact, one of the lowest recorded cycles ever. Indeed one can venture to say that had it not been for human interference and the building of dams there would have been greater suffering in the downstream states.

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PART III

THE UTILIZATION OF THE WATERS OF THE NILE

1

THE EARLY SETTLERS MEET A HOSTILE RIVER

The time of man's first appearance in the Nile Valley is not known with any certainty. It could well have been over one million years ago. The earliest record of human-made implements, the so-called pebble tools, comes from along the river banks. The implements are found in the torrential sediments of a locally-fed ephemeral river which occupied the modern valley long before the Nile affected a connection with its African sources. The few flint tools found in these early torrential sediments of the Armantian Pluvial were picked near Luxor by Biberson et al (1970). There is little that can be learnt from these primitive tools which may be, in the opinion of some authors, nothing but naturally flaked pebbles.

The earliest definitive records of man in the Valley of the Nile are dated many hundreds of millenia later and are found in the torrential deposits of another pluvial, the so-called Abbassian. These early settlers encountered a river which was totally different from the one we know today. When these settlers appeared on the Egyptian scene some 400,000 years ago the magnificent and vigorous early Nile, the Prenile, had ceased to flow. As we have already seen in Part I (Fig. 1.17) the Prenile was the earliest river to reach Egypt with a sub-Saharan African connection. This connection occurred some 800,000 years ago and brought a copious river which carried an enormous load of suspended sediment, depositing it along the banks of the valley and delta which extended then far beyond their present-day limits. After the cessation of that river some 400,000 years ago it was replaced by a considerably less competent, flickering river, the Neonile, which carried smaller amounts of water than its predecessor and maintained only a tenuous and sporadic connection with its African sources. It lost this connection many times and when it was resumed the river never came back with the length of duration or competency of the Prenile. The following table (to be read in conjunction with Fig. 1.17) gives the successive Nile stages and the intervening episodes as well as the cultures corresponding to each of these stages.

The Neonile rivers which preceded the modern Nile were not predictable. During their duration of close to 400,000 years their floods fluctuated greatly when the African connection was in effect. When this connection was lost they derived their water from local rain which came mostly in spates, irregularly and in torrential form. The environment of these rivers was indeed hostile. The deserts, by contrast, had a more favorable environment especially during the pluvial periods when increased rainfall and a rising water table furnished many areas with a permanent supply of water. It is no wonder, therefore, that it was in the desert that history began. Animal domestication and agriculture were developed in the desert, millenia before they found root in the valley of the Nile.

Age (10^3)	Nile Stages (& intervening wadi deposits)	Pluvials (Paleolithic)	Archeology
	modern Nile	Holocene	
10	gamma Neonile beta Neonile		Late
70	Erratic Neonile Intervening gravels	Saharan	Middle
	Wadi gravels alpha Neonile	Abbassian II	Early
400	Wadi gravels	Abbassian I	
?800	Prenile		
?1000	wadi gravels	Armant	?Pebble tools

Inspite of the hostility and unpredictability of the river, however, the early hunters and gatherers who first came to settle in Egypt must have found the valley of some use. They were attracted to the banks of the river from the earliest of times; the remains of some of the oldest races which inhabited Egypt are found in the deposits of the rivers which occupied the Nile Valley during the early as well as the Middle Paleolithic periods.[1] Man-made flint tools (Fig. 3.1) are found in the deposits of the rivers which filled the valley during the earlier stages of the Neonile.

The earliest of these tools are dated between 400,000 and 200,000 years ago and belong to the Early Paleolithic (Acheulian). They are found in abundance in the deposits of the ephemeral local river which occupied the valley after the waning of the first of the Neoniles with an African connection (Fig. 1.17). Little is known about the life style of this early man; no skeletons or living floors which belong to this early race of men have been found so far. The same can also be said about the Middle Paleolithic (Mousterian and Aterian) men who followed these earlier men. Their tools are found in the wadi deposits which interfinger and alternate with the deposits of the low and erratic Niles with African connections which followed the earlier Neonile. The tools are dated between ?200,000 and 50,000 years ago. Some of the tools are *in situ* but many are rolled and seem to have been transported from their original place. No tools have been found

[1] The Paleolithic is a stage in the early history of man when he depended on hunting and gathering activities in which he used crude implements of stone. The Paleolithic is divided into an early, middle and late epoch depending on the type of implements and the technique used in their fashioning. The duration and date of this stage varies from place to place. In sub-Saharan Africa it could well have lasted for more than one million years. In Egypt it lasted for a considerably shorter time, from about 400,000 years ago to about 12,000 years ago. The Early Paleolithic (sometimes called Acheulian after the type locality in France) lasted probably about 250,000 years, the Middle Paleolithic (divided into an earlier Mousterian and a later Aterian after the type localities in France and Algeria respectively) about 130,000 years and the late Paleolithic about 20,000 years.

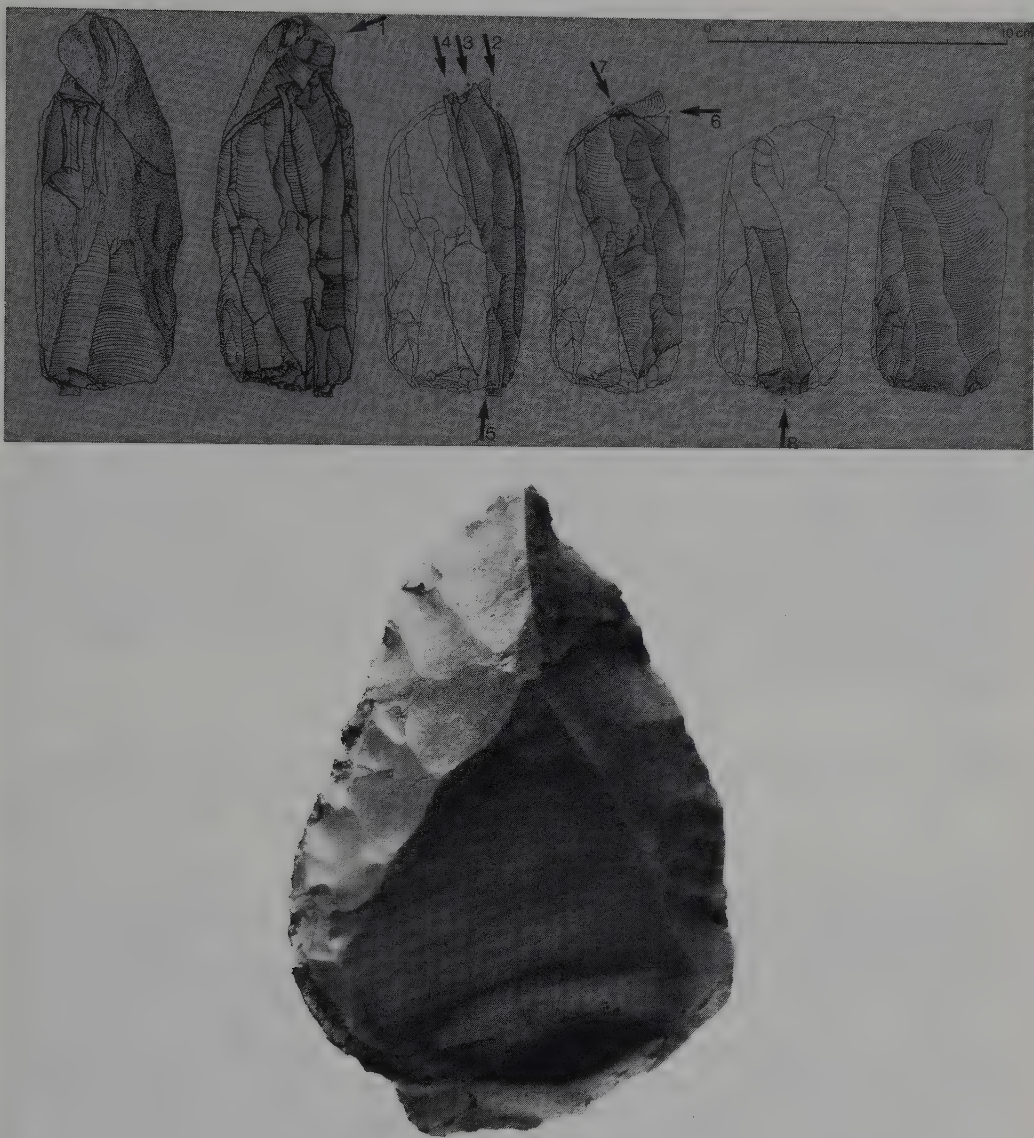

Fig. 3.1. Tools of flint; Top: early Paleolithic hand axe from Thebes; Bottom: late Paleolithic tools from Sitra, Qattara depression. The bottom panel is from: Cziesla, E. & R. Kuper 1989.

in association with a living floor or structure of any kind, nor with any faunal or floral remains. There is indeed very little evidence that can help reconstruct the nature or the economic base of the societies of these early men.

These tools were made from flint which was fashioned in workshops which lay in the vicinity of outcrops carrying this stone. Some of the oldest of these workshops were in Nubia and are dated as early as the Early Paleolithic by Guichard & Guichard (1968). During the Middle Paleolithic these workshops became greatly developed and their source material was worked

out in an elaborate way. A flint quarry pit recently discovered by Vermeersch and associates (1984, 1986, 1989 & 1990) in the Qena area (Fig. 3.2) was exploited on a grand scale during these early times. The digging activities included ditches, shafts and underground galleries with subterranean connections making this quarry one of the oldest mining operations in history. The size of the quarry, the complexity of the methods of extraction (which resulted in the exhaustion of the raw material sought in that mine), and the large heap of debris left behind allow one to conclude that the population of this locality during Middle Paleolithic times must have been sizable and probably in the range of several hundreds.

The most extensive and best preserved Early and Middle Paleolithic sites are known outside the Nile Valley in the deserts of Egypt, which were considerably wetter during the Abbassian and the Saharan Wet Phases which coincided with the Early and Middle Paleolithic cultures respectively. The Nile Valley did not seem to have had an advantage over the desert environment. In fact, it was a less attractive place for living; during most of the Early and Middle Paleolithic the river was either ephemeral receiving torrential rains in spates or else was low and erratic. In the desert, life seems to have been considerably easier, as can be seen from the bounty of wild life remains in a butchering site of a Middle Paleolithic desert settlement (Fig. 3.3). Faunal remains in this site include the white rhinoceros, extinct buffalo, extinct camel, the large gazelle *Gazella dama*, the small red-fronted gazelle *Gazella rufiformis* and a zebra, indicating a rich savanna landscape and a luxuriant environment receiving probably about 500 millimeters of rain per year (Wendorf & Schild 1980).

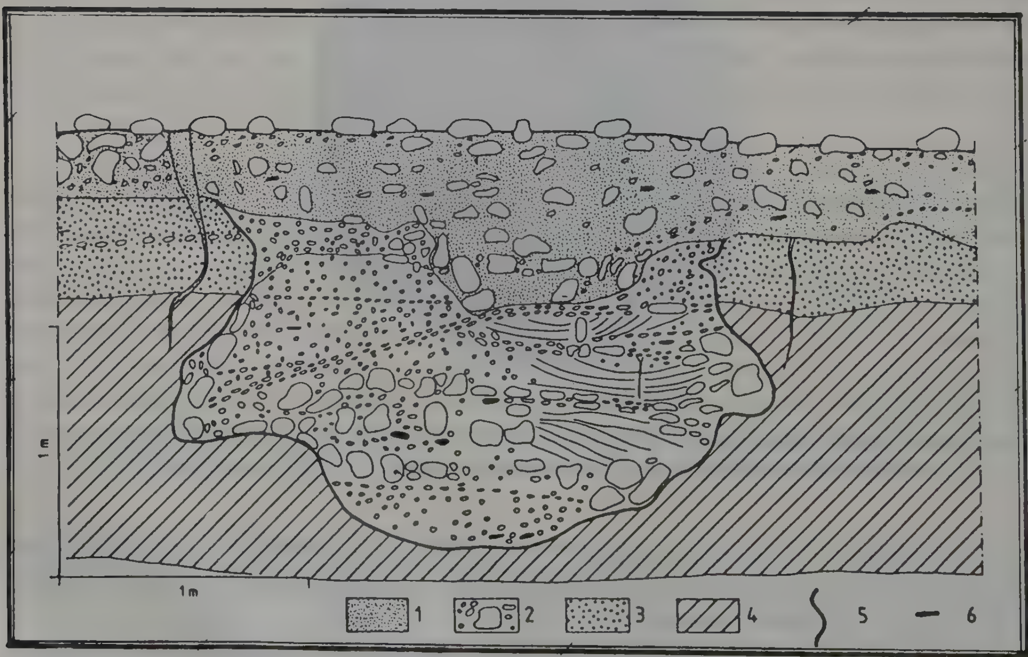

Fig. 3.2. Quarry of flint at Makhadma, Upper Egypt. 1. loose wind-blown sand, 2. man-made heterogenous fill, 3, 4. consolidated sand and gravel substratum, 5. edge of Paleolithic ditch, 6. Middle Paleolithic artifacts (after Vermeersch 1990).

The earliest living floors from the Nile Valley belonged to the peoples of the late Middle Paleolithic and the Late Paleolithic (35,000–12,000 years ago) who seem to have camped around the Nile in Nubia and southern Egypt when they abandoned the desert after it had dried up with the advent of the last glacial age. Several distinct cultural groups converged on the valley from the desert after the drought, each occupying a section of it. When these cultural groups came to the valley they found a non-beneficient river which was seasonal and essentially torrent-fed by the scant summer rains of Ethiopia. Like the present-day River Atbara, the River Nile had no running water during the non-rainy season of the year but only numerous and occasionally deep and extensive pools. The groups which converged on the river entered into competition, and occasionally into conflict, for the meagre resources of the river. Times were bad. The climate was cold and extremely arid. The river was unpredictable. Living in its shadow must have been very difficult, for one needed to cope with its flickering moods of occasional waves of high water followed by long periods of drought.

Survival in this ungenerous environment was conditional on finding new sources of food besides the hunting of large mammals which must have been decimated in this harsh environment. From early on much use was made of freshwater fish and, from about 18,000 years ago, of ground-plant foods. The use of the last two resources was an outcome of increasing stress and competition. Fish became an important element in the diet of Nile dwellers from at least the Late Paleolithic (Van Neer 1989). The earliest fishing took place in the shallow pools of the floodplain which were left behind after the flood had receded; some Nile fish species can survive in these pools even after they are partially or completely desiccated. *Clarias* (catfish), *Protopterus* (lungfish), *Tilapia* and *Barbus* are all types of fish which can have a prolonged stay in the small pools of the flood plain. The first two genera can survive complete desiccation while the latter two need a minimum supply of water and oxygen. Fishing from the main river came only at a considerably later time in post Late Paleolithic time.

Evidence of times of conflict, aggression and strife comes from a Nubian cemetery discovered at Gebel Sahaba, near Wadi Halfa (Nubia) dated at about 14,500 years before present; stone projectile points are found embedded in the bones of most of the skeletons. These are seen as the cause of death. Some 40 percent of the burials have such artifacts associated with them; they include men, women and children.

In an older burial site in Wadi Kubbaniya to the north of Aswan, dated older than 20,000 years before present, the skeleton of a young man also shows evidence of a violent end. He did not only survive two injuries at about age fifteen but also a left epicondylar wound before his death in his early twenties by a spear in the back (Wendorf & Schild 1986). The physical attributes of the Kubbaniya skeleton were described by Stewart et al (1986). They are similar to those of all other skeletons found in the Nile Valley of the Late Paleolithic. They suggest a race of robust *Homo sapiens* which inhabited north Africa from the Nile to the Maghreb. The Kubbaniya burial was placed in a long rectangular trench or pit dug to unknown depth. The body was placed in the pit face down, head to the east and arms to the side. The position of the legs is not known, but the position of the proximal portion of the right femur suggests that the legs were extended. A face-down extended position is not common among late Paleolithic burials.

The oldest skeleton discovered in Egypt was found in Nazlet Khater near Tahta, upper Egypt (Vermeersch, Gijselings & Paulissen 1984). It is dated between 35,000 and 30,000 years ago. The burial is of a young man, seventeen to twenty years old, who was probably worked to death

in a nearby flint quarry. The skeleton (Fig. 3.3) was described by Thoma (1984). It lay in a 160 centimeter long narrow ditch aligned from east to west. The head was slightly turned to the left pointing to the west and the legs were in an aslant rising position. The right arm was stretched along the body, while the left one was folded so that the hand rested upon the lower part of the pelvis. The covering consisted of several boulders, some more than 40 centimeters in diameter. A tool, which had been laid carefully upon the bottom of the grave, dates the burial as contemporaneous with a nearby flint quarry.

More adverse times came with the period of extremely high and wild floods of the Nile that extended for 500 years from 12,500 to 12,000 years ago. These occurred as a result of the dramatic climatic change affecting the Equatorial Lake Plateau which caused an increase in the flow of the Nile and made life along its banks almost impossible. The result of this period of high floods was the conversion of the valley into a marginal place; a large number of its people were forced to migrate to the desert which started at that time to receive the scanty rains of the Holocene (Nabtian) Wet Phase. High floods can bring enormous stress. I cannot find a better description of the effect of a high flood on the psyche of the dwellers of the valley than the testimony of William Willcocks (1904) describing the flood of 1887 A.D. which was not as high even as the flood of 1878, let alone those prehistoric floods which are our concern here.

> "The terror reigning over the whole country during a very high flood is very striking. The Nile banks are covered with booths at intervals of fifty meters. Each booth has two watchmen, and lamps are kept burning all night. Every dangerous spot has a gang of fifty or one hundred special men. The Nile is covered with steamers and boats carrying sacks, stakes and stone; while the banks along nearly their entire length are protected by stakes supporting cotton and Indian cornstalks, keeping the waves off the loose earth of the banks. In a settlement of a culvert in the Nile bank north of

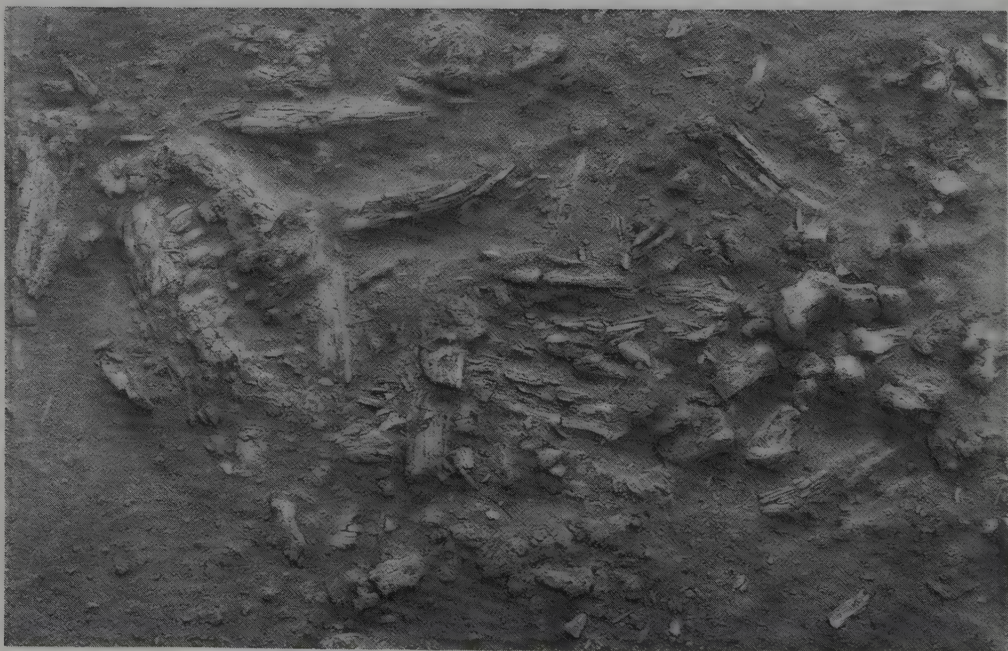

Fig. 3.3. Butchering site in Bir Tarfawi, Western Desert, Egypt (after Wendorf, Close & Schild 1985).

Mansourah in 1887 I witnessed a scene which must have once been more common than it is today. The news that the banks had breached spread fast through the village. The villagers rushed out on to the banks with their children, their cattle and everything they possessed. The confusion was indescribable. A narrow bank covered with buffaloes, children, poultry and house-hold furniture was breached. The women assembled around the local saint's tomb, beating their breasts, kissing the tomb, and uttering loud cries, and every five minutes a gang of men running into the crowd and carrying out the first thing they could lay hands on wherewith to close the breach. The fellahin, meanwhile, in a steady business-like manner, plunged into the breach, stood shoulder to shoulder across the escaping water, and with the aid of torn-off doors and windows and Indian cornstalks, closed the breach. They were only just in time. This is the way the fellahin faced a breach".

This vivid description of the terror of living with one high flood makes it easier to understand how 500 years of successive and considerably larger floods had turned the valley of the Nile, at the beginning of the retreat of the ice of the last glacial, into a very hostile place to live in. The valley was indeed a place to avoid if that were possible. In the meantime, large parts of the deserts of Egypt opened for settlement as the monsoonal rain front of the Holocene Wet Phase pushed its way northward. An estimated annual rainfall of about 100 to 200 millimeters per annum became normal over the deserts of Egypt. This new frontier was not a generous environment either. But it was considerably better than living in the shadow of an angry river. Access to water must have been a pre-eminent preoccupation of the people who went to make

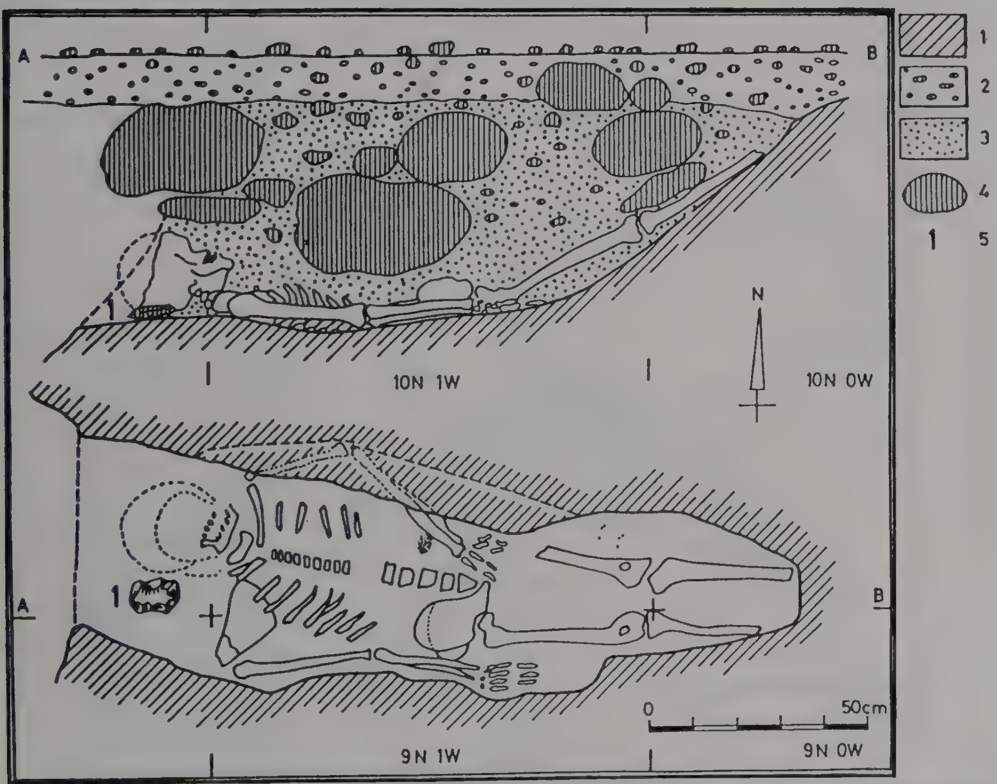

Fig. 3.4. Skeleton Nazlet Khater man. 1. silt, 2. gravel, 3. wind-blown sand, 4. boulder, 5. bifacial axe (after Vermeersch et al., 1988).

use of this new environment. Nevertheless, the new frontier seems to have been one that attracted immigrants.

The people who settled in these desert areas reared domestic cattle, intensively collected wild cereals of African origin and later cultivated cereals and raised sheep. They lived first as nomadic pastoralists but soon established semi-permanent villages, constructed public works (large wells) and produced and peddled in luxury goods indicating increasing social organization. The oldest village known in Egypt was discovered in the desert at Nabta, south Western Desert (for location see Fig. 3.7). It is dated about 7000 B.C. Figure 3.5 shows the plan of this excavated village with its houses arranged in two rows. Many of the houses had hearths and storage pits, and the village had a deep walk-in well at its edge; it indeed had all the makings of a village (Wendorf, Close & Schild 1985).

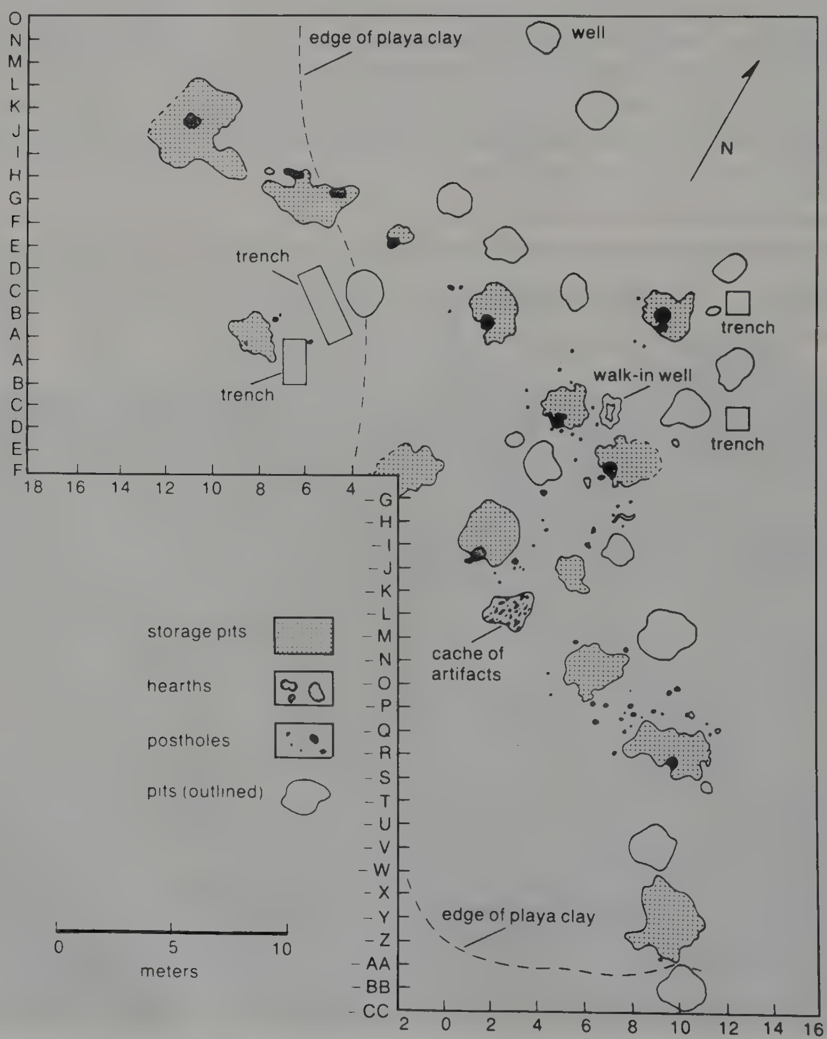

Fig. 3.5. Plan of oldest village in Egypt at Nabta, south Western Desert (after Wendorf, Close & Schild 1985).

The prehistoric studies of the desert regions west of the Nile Valley reveal that the domestication of cattle started around 9000 B.C. Domestic cattle seem to have been present in the Sahara as early as, if not earlier than, in Turkey and southeastern Europe raising the possibility of a separate African effort to domesticate cattle at about the same time that the process began in the Near East (Braidwwood 1975). Cattle bones which are considered domestic on ecological grounds are described from the Nabta Playa and Bir Kiseiba (south Western Desert of Egypt about 120 kilometers west of Abu Simbel). The early desert pastoralists were also considerably more advanced than the Nile dwellers of the time in that they preceded them in the use of pottery.

The communities which lived in the Egyptian desert intensively collected sorghum and other cereals of African origin, stored large quantities of their seeds in pits and ground them into flour by grinding stones that are found in large numbers in all the desert settlements. This may be taken as an indication that these desert communities either practiced agriculture or were very close to it. If these communities did practice agriculture then it can be stated that agriculture and its corollary of village settlement began in the deserts of Egypt two millenia before it began in the Nile Valley, and may be as old as the oldest known agriculture in the world.

The history of the development of agriculture in Egypt seems to parallel that in the Near East's Fertile Crescent (area extending from the coast of the Levant to the footslopes of Anatolia and Iraq (Fig. 3.6)). The Fertile Crescent was the primary habitat of wild wheat and barley and the place where these cereals were first domesticated. In this area the development of agriculture

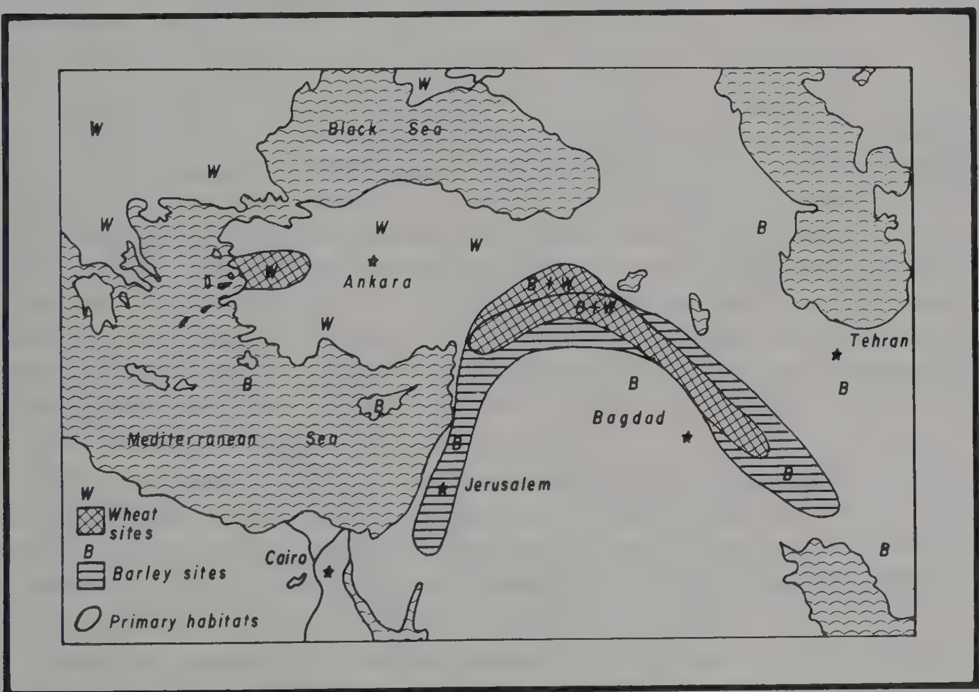

Fig. 3.6. Map of the fertile crescent showing the area of primary habitat of wild barley and wheat where they were first domesticated.

was preceded by an initial stage of intensive collection of wild cereals around 10,000 B.C. In Palestine the Natufian communities hunted, herded goat and gazelle and harvested wild emmer wheat. Grindstones were used to convert the grain to flour. The intensive collection of wild cereals was followed by the sowing of cereals outside their natural habitat, a practice first traceable to northern Syria in ca. 9000 B.C. Einkorn, a wheat which grew wild in the foothills of the Taurus and Zagros Mountains to the north and east, was found in far away places indicating that the inhabitants must have been cultivating the plant intentionally. The first cereals of fully domesticated type were those from Jericho in the Jordan Valley, dated around 8000 B.C.

2

THE RIVER BECOMES BENEFICIAL; AGRICULTURE COMES TO THE NILE VALLEY

The advent of the Holocene Wet Phase had its impact on the Nile; it changed it into a perennial and a more predictable river under which life became more tolerable than in earlier times. At the start of the wet phase the course of this new river in Egypt, like its seasonal predecessors, was obstructed by numerous impediments upstream of the Qena bend. These were worn down in the early phases of the new river which soon assumed its modern gradient about 9000 B.C. At the same time, the rise of the sea level caused by the retreat of the great ice sheets of the last glacial caused the newly-graded river to aggrade its bed. The wearing down of the obstructions made possible the easy flow of the waters of the river to the reaches north of the Qena bend and stopping the swelling of the river to the south that had resulted from the backwater effect of these obstructions. Although numerous dry periods interrupted the Holocene Wet Phase and affected the flow of the Nile, it can safely be said that the period from 9000 to 6000 B.C. was one characterized by a copious flow, easily exceeding 250 billion cubic meters per year.

A crucial change in the climate and in the volume of the river occurred after the end of the middle Holocene drought (6000–5200 B.C.). After that drought the river basin received lesser rains and the discharge of the river was reduced to an average of less than 200 bilion cubic meters per year. Floods of this size are high by modern standards, but they were adequate for the exploitation of the flood plain of the river without resort to technological innovations. It is highly probable that the middle Holocene drought drove large numbers of the Saharan dwellers to the valley of the Nile which must have seemed to these knowledgeable people a perfect place for farming. The river indeed had become a suitable place for agricultural use. The height of the flood ensured that the water would reach the flood plain without the use of any lifting equipment; the annual deposition of the silt ensured the perpetual fertility of the land; and the rise and fall of the river assured its thorough drainage.

The oldest agricultural sites in Egypt are found on the western delta margin at Merimde and in the Fayum depression in scattered ancient lake settlements (Fig. 3.7). These Neolithic settlements are dated ca. 5200–4000 B.C. Several theories have been advanced as to the sources which could have influenced the introduction of agriculture in Egypt; these include autochthonous development and the influx of settlers from without.

The theory of autochtonous development assumes that the Saharan communities who were forced out of their habitat by the Holocene drought and who came to settle in the Nile Valley had a great influence on the native dwellers conveying to them their experiments in the domestication of animals and plants. The advocates of this theory substantiate their arguments

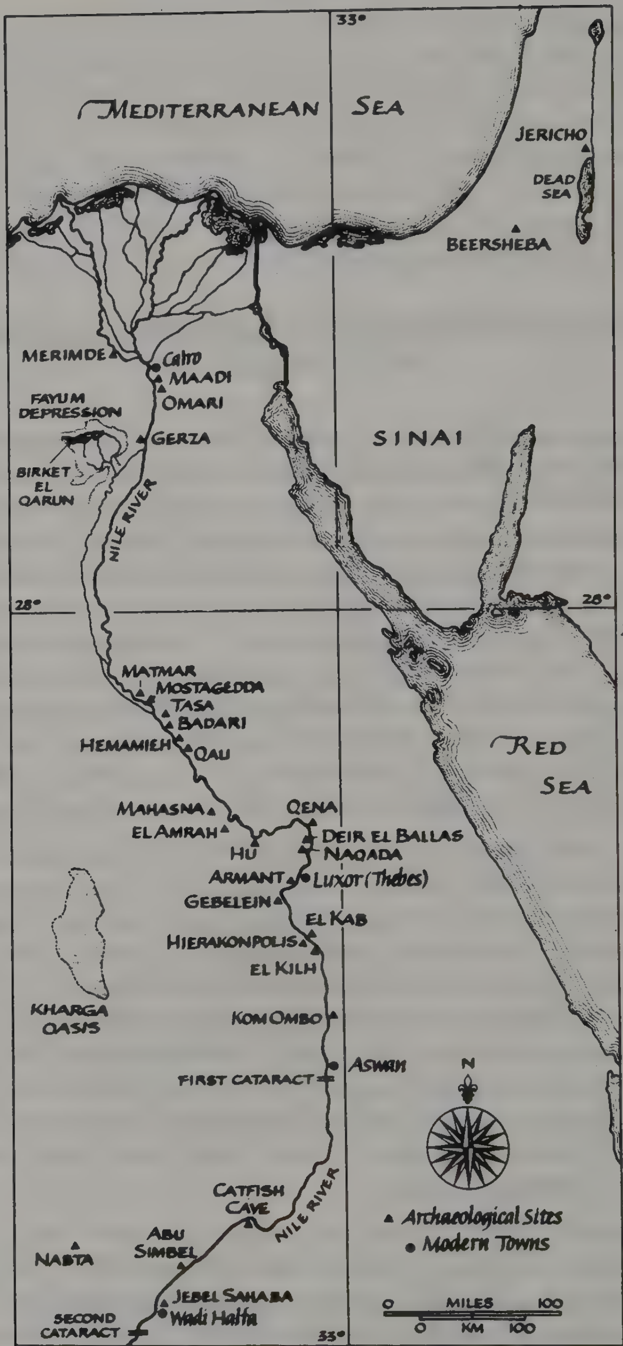

Fig. 3.7. Map of Predynastic sites (redrawn from Hoffmann 1979).

by pointing to the similarity between the tools of the agricultural communities of the south Western Desert of Egypt and those of the old Neolithic settlements of the Nile Valley; both communities had strong hunting and gathering components in their tool kits. Agriculture seems

to have developed slowly in Egypt. As late as Predynastic times Egypt was still an amalgamation of desert herders, farmers, Nilotic fishermen, and hunters and gatherers. They supported themselves through a mixture of herding, fishing and farming even though they lived in villages and towns some of which reached large dimensions and featured buildings of monumental proportions (Hoffman 1979).

The theory that agriculture came with the influx of settlers probably from southeast Asia has its greatest support in the fact that the spectrum of domesticates characteristic of Egyptian agriculture belongs to the same assemblage as that of the Fertile Crescent (Zohari 1986). The oldest discovered domesticated cereals in the Neolithic communities of the Nile Valley were wheat and barley as in the Fertile Crescent. Contrary to earlier reports these two cereals were not known to the Saharan communities of the south Western Desert of Egypt who cultivated sorghum, millet and other cereals of African origin (Wendorf et al. 1992). In light of this new report it is difficult to conceive that the art of food production was introduced from the desert.

Whatever theory one may accept with regard to the introduction of agriculture in Egypt it is certain that the new settlers of the valley found the flood plain of the river, after its uncovering upon the retreat of the flood waters, a perfect place to begin farming and to reap at least one crop a year. This practice soon led to the development of the system of basin irrigation which over the years evolved into an elaborate system of dikes, artificially delimited basins and take-off canals. It was destined to last for several millenia. It is indeed enigmatic that the development of this system started in the relatively poor section of upper Egypt stretching south from Abydos, and not in the richer part of the valley (Wilson 1955). It is possible that the relatively limited natural resources of that area encouraged dependence upon an intensive farming economy at an earlier date than occurred elsewhere in Egypt. The small natural basins found there were also more easily worked out into manageable units than were the larger ones farther north. The high productivity of these basins, when managed on a local level, provided the necessary foundation for and instigated the process of the emergence of a central authority on the provincial (nome) level and finally on the state level (Trigger 1984). By late Predynastic time the ancient Egyptian hydraulic civilization with all its distinctive aspects — such as the state, kingship, the royal mortuary cult, and true political capitals with temples, palaces and royal cemeteries — had developed.

3

BASIN IRRIGATION

"They take the flow o' the Nile
By certain scales in the Pyramid; they know,
By the height, the lowness, or the mean, if dearth
Or foizon follow: the higher Nilus swells,
The more it promises: as it ebbs, the seedsman
Upon the slime and ooze scatters the grain,
And shortly comes to harvest." Shakespeare in Anthony and Cleopatra.

Artificial basin irrigation was developed to benefit from the natural seasonal pattern of the discharge of the Nile by regulating the flow of its flood waters to the flood plain of the river. The system was based on the submergence of the plain with water starting from early August. The plain was divided into basins which varied in size from 2000 feddans in upper Egypt to 20,000 feddans in the broad deltaic areas; they were fed by take-off (feeder) canals. These canals were ingeniously designed to make the maximum use of the water of the flood. With a bed level which was midway between low Nile and ground level, they had a natural downsteam slope which was gentler than that of the Nile. Each canal fed an average of eight basins in succession; the amount of water entering each basin was controlled by masonry regulators provided on each of the transverse earthen dikes which separated the basins (Fig. 3.8). The system assured that all the basins were evenly watered. The average depth of water in the basin varied locally according to flood volume. It ranged from 1.25 to 1.5 meters in the nineteenth century in Upper Egypt. In the delta the depth was less, the flood arrived late and water remained in the basins for a shorter time than in the valley. Generally speaking, the water stayed in the fields for 40 to 60 days after which the basins were drained off. This annual submergence with water charged with alluvium made the basin levels very even. In years of poor flood, each basin was drained not into the river but, for economy in water utilization, into the next basin downstream (for a description of the system of basin irrigation see Willcocks & Craig 1913 and Hamdan 1961). By controlling the rates of filling and emptying of the basins the Egyptians were able to effectively irrigate their lands with floods varying in size. As long as the system was maintained Egyptian agriculture was relatively insensitive to a certain degree of fluctuations in the annual discharge of the Nile.

The system of basin irrigation is old. It has become a tradition, perpetuated by Herodotus and Diodorus, to give the credit for the first major irrigation work in Egypt to King Menes, the founder of Dynasty I in 3100 B.C., who is said to have dammed the Nile somewhere in the vicinity of Memphis to protect the city from the overflowing of the Nile and also as part of its defence. The exact location of this dam is not known with certainty. Jeffreys (1985) identifies the dam with the one near Koschesch (Qusheisha), about 60 kilometers south of Memphis,

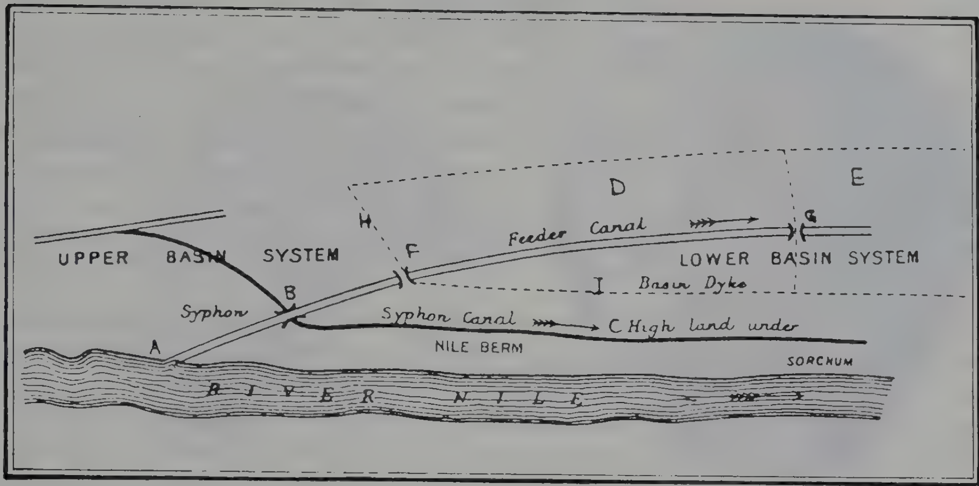

Fig. 3.8. Plan of basin irrigation. A. head of basin canal, B. syphon of syphon canal, C. high land under sorghum, D, E. basins, F, G. regulators, H. transverse dike, I. longitudinal dike (modified after Willcocks and Craig 1913).

which forms today a flood barrier for the whole of the Giza province. The dam has a maximum height of about 15 meters and a crest length of some 450 meters. Jeffreys (1985) also mentions many other possible sites that could have been the site of the old dam. According to Herodotus the river was diverted to the west after the building of the dam. There is indeed evidence that the Nile itself or a major branch of it ran along the Western Desert edge between Giza and Abu Sir. All along the cliff which borders this stretch there are remains of revetted quays, large piers and harbor installations which seem to indicate that a water course must have run at its foot slopes (Goyon 1971 and Zahi Hawas, personal communication).

Inspite of this tradition which gives credit for the first irrigation work to King Menes there is indication that artificial irrigation was known in older times and that it was fully developed by the time of the unification of Egypt and the accession of King Menes. Already at the time of the scorpion king, the last of the Predynastic kings, some kind of artificial irrigation must have been practiced, for the main part of the mace-head of the king (Fig. 3.9) depicts an irrigation work performed under his supervision. The central figure on the mace is the king standing with hoe in both hands. In front of him is a man carrying a basket to hold the earth, and another holding a bunch of ears of corn. Behind him are two fan-bearers and the open country with growing plants. Below the king are represented the irrigation works which he is inaugurating. Two men are engaged in ?cutting the banks on opposite sides of a canal or ?excavating a canal (Emery 1961). Behind one of them there is a palm tree growing in an enclosure surrounded by reeds bound with cords.

The first attempt at artificial irrigation took place in upper Egypt, but soon it moved to the north where the flood plain of the western bank of the river was divided into basins. This was done by reinforcing the longitudinal natural levee of the western bank of the river and building cross dikes which tied it to the desert. Intake canals were then built to allow the flood waters into these basins to saturate the soil and retain the water even during brief flood crests. Until Middle Kingdom times almost the entire eastern bank of the river was left untouched and was allowed

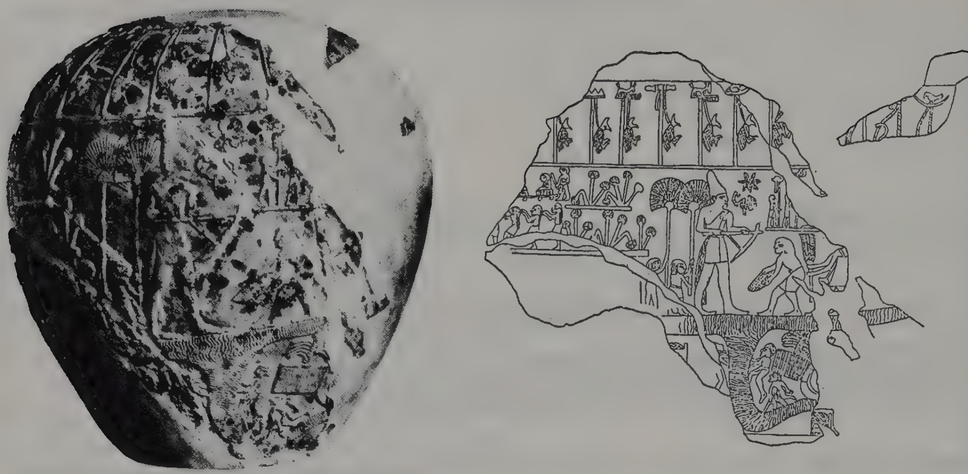

Fig. 3.9. Macehead of King Scorpion.

to be swept by the floods. This seems to have acted as an escape for the waters of the extremely high floods of Old Kingdom times.

Measures to increase the use of the waters of the Nile were introduced during Middle Kingdom times in the wake of the disastrous period of lower Niles of the First Intermediate Period. These included the building of a longitudinal dike along the eastern bank of the river to confine it to its trough. This increased the arable land of Egypt by adding to it the lands on the east bank. It also raised the level of the flood as it became confined in its trough, making it possible for floods with lower crests to override the flood plain. On the other hand, floods with higher crests, which became common during Middle Kingdom times, exposed the lands around Memphis and the delta region to disastrous consequences. To obviate this, King Amenemhat I (named Moeris in Herodotus History) used the Fayum depression as an escape for the dangerously higher floods. He widened and deepened the natural channel which led to the depression and regulated the entry and exit of the water into it by a series of gigantic dikes. This undertaking was so successful that the conversion of the Fayum depression into a reservoir (Lake Moeris) was long considered by the ancient world as one of its greatest wonders. The flood was led into the depression when it was high, and was returned to the river when it had come to an end. By this means the lake was insured against being filled to dangerously high levels by a succession of floods. The dikes of entry and exit were cut only in times of emergency (Shafei 1960).

The pharaohs of the twelfth dynasty devoted a great deal of attention to the Fayum Province. They were able to reclaim close to 21,000 acres of land at the entrance of the depression which lay above contour twenty-one meters, the new level of the regulated lake (Fig. 3.19). These lands were walled and added to the king's domain. During the reign of Amenemhat III they became the seat of government. Among the prosperous towns of the region was Crocodilopolis (present-day Medinet el-Fayum) so named by the Greeks after its temple devoted to the worship of the crocodile-god Sobk. Numerous monuments attest to the importance of the province. In addition

to the two pyramids at Lahun (Senwosret (Sesotris) II) and Hawara (Amenemhat IV?) built on the northern cliff of the channel, there are the obelisk of Senwosret I at Ebgig, the two colossal statues of Amenemhat III (the famous Biyahmu monuments which were thought by Herodotus to have stood in the midst of the lake on stilts some 50 fathoms high) and the famous Labyrinth building which seemed to have been the seat of the central government responsible for the administration of the nomes. This latter building, which has now fallen into rubble, was on the northern bank of the channel and was impressively large; its dimensions were 250x300 meters and included a hall for each of the nomes of Egypt where its gods were enshrined and worshipped.

The basin system of irrigation was designed to capture the flood waters for the cultivation of a single winter crop. After the harvest of the crop in the spring, the basins were left fallow until the arrival of the next flood. From the earliest of times high lands which were not flooded by the river were the only lands cultivated also during the summer. Most of these high lands supporting two crops lay on the longitudinal dikes bordering the river. They were irrigated by water which was lifted from the river or from especially dug wells (Fig. 3.8). As early as Old Kingdom times there were attempts to enlarge the area of land capable of yielding two crops a year. This was possible in areas where the subsoil gave a plentiful supply of water. It is in these areas which permitted intense cultivation throughout the year that we find all the ancient capitals of Egypt (Willcocks 1904). Abydos had the finest subsoil water in the Nile Valley; Memphis had an excellent supply; Thebes had the only good subsoil water along the whole of the right bank. Good subsoil water was indeed a source of wealth and surplus; for while one crop was sufficient to provide food supplies for the population of Egypt during the majority of the years, it certainly did not generate a substantial surplus. Basin irrigation was an advanced stage of subsistence agriculture. The giant stride into a new era of wealth was made when a second growing season during the summer months was added. This became increasingly common with the introduction of lift irrigation starting from New Kingdom times.

Aside from these attempts it can be said that, on the whole, land use in Dynastic Egypt shows a simple pattern of winter agriculture largely confined to the basins which were flooded by a crude but effective system of irrigation. Dynastic flood irrigation technology was ingenious in that it made full use of what nature had bestowed on the land, but it was, nevertheless, rudimentary and conservative. The introduction of perennial irrigation was a very slow process. It took several millenia to introduce a simple lifting device such as the shaduf. The Old Kingdom plough made up of a long wooden aard and drawn by a team of oxen has not changed over the centuries and can still be seen today in many Egyptian fields (Figs 3.10 & 3.11). This conservatism also applies to the inventory of cultigens which remained the same throughout Dynastic times; the first new introductions came in Ptolemaic if not Roman time. It was perhaps in the area of animal domestication that there is some indication of innovation (Butzer 1976 & Boessneck 1989). There were attempts to domesticate the hyena, addax, gazelle and ibex in Old Kingdom times. Among the new introductions were the Asiatic wool sheep in Middle Kingdom times to replace the traditional fleeceless variety, the horse in Hyksos time and the camel as a beast of burden in Ptolemaic time.

Part of the conservative nature of Ancient Egyptian civilization goes back perhaps to the fact that throughout almost the entire length of the Dynastic period the river was relatively high and predictable. Periods of excessive low and high Nile were short, and they were periods of great

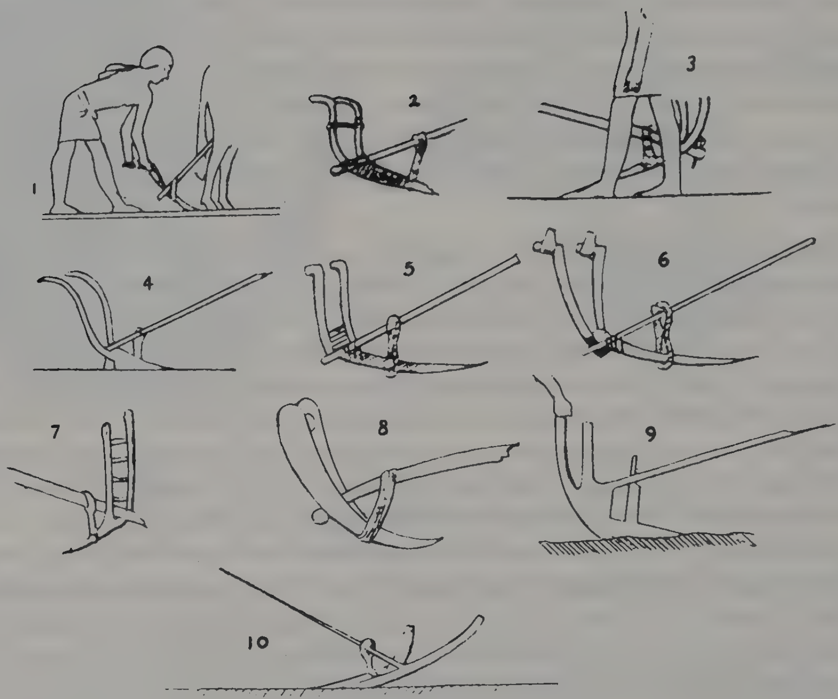

Fig. 3.10. Predynastic and early Dynastic ploughs used in the field (after Harmann, F. 1923).

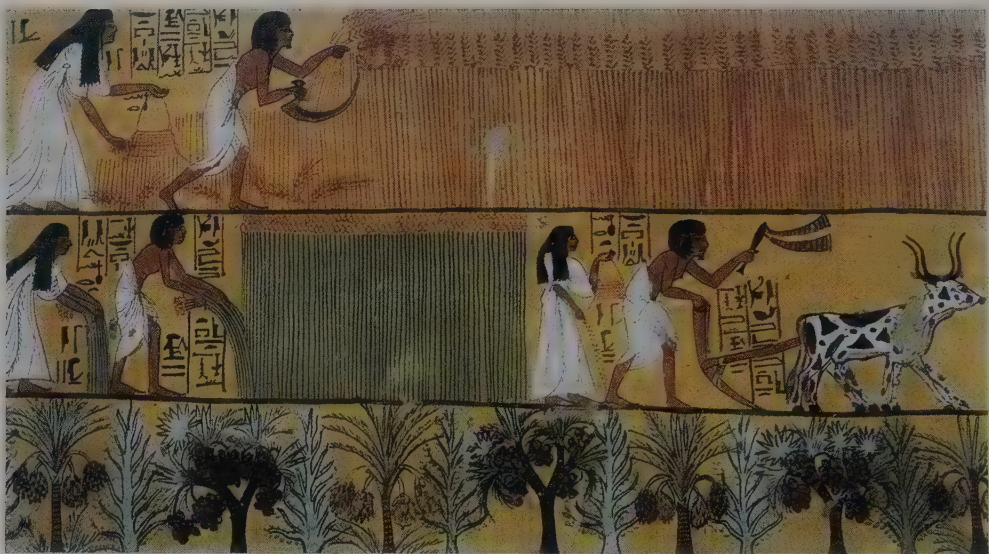

Fig. 3.11. Tomb of Sennedjem, Deir el-Medina, Thebes showing Sennedjem and wife working in the field and using a plough (type 9 in Fig. 3.10).

stress with which the bureaucracy in Dynastic time was not equipped to cope. We have already given several instances from Dynastic Egypt in which repeated Nile failures brought disaster on a scale that led to the break-down of the political and social order.

Outside the great irrigation works carried out by the engineer kings of the Middle Kingdom, agriculture was administered in Ancient Egypt on a local rather than on a national scale. No centralized canal network was ever achieved in Dynastic Egypt and, as we have seen, no lifting equipment was devised except at a very late time. The digging and maintenance of the canals and the reinforcing of the dikes were public service works that were carried out on the local level by mobilized labor. This system of labor, named "corvée", and was in force until the latter years of the nineteenth century when it was abolished.

Among the few activities which assumed a national and centralized nature were the measurement of land and the recording of the height of the flood; these formed the traditional link between tax rates and the potential harvest determined, to a large extent, by the land and the flood. After the inundation the land was "measured and counted" as reported by Ramses III to his father. Surveying scenes of the "counting" process are common in ancient Egypt (Fig. 3.12). As most of the lands were annually submerged by inundation and some had their areas diminished by the scouring action of the river while others had them increased by deposition, their boundaries had to be frequently retraced and their areas recalculated in order to ensure the proper incidence of taxation. Hence the art of land measurement was practiced in Egypt from very early times. Ordinary measurements of land were made with a twisted cord, the length of which was the *khet* or 100 cubits of 0.525 meter, i.e. 52.5 meters. Areas were calculated in *setat* or square *khets*, a *setat* or square *khet* being 100 square cubits of land, each of which was 100 cubits long by one cubit broad. This area came to be known as the *aroura*, which is a Greek word originally meaning ploughed land. It was equal to 100x100 cubits or ca. 2750 square meters or two thirds of a modern acre. For taxation purposes registers of ownership and area were kept. They were reviewed annually. Cadastral maps, however, were unknown in ancient Egypt.

Nilometer measurements were closely related to the fecundity of the land. Not only did they determine the area of land that was to be inundated and the duration of the flood but they also helped in monitoring the flood and devising a system of warning when it became dangerously high. According to Diodorus, flood warnings were sent to the population from the nilometer at Memphis by swift rowers, one after another, who were able to outpace the approaching flood and report the latest level at the capital. A watch-tower at Memphis sent letters by courier from one city to another reporting on the rise of the river and the beginning of its decrease.

3.1. The Introduction of Lift Irrigation and the Reclamation of the Fayum Province

Water lifting in the Old and Middle Kingdoms of Ancient Egypt was done by the manual transport of pots and buckets. It was only in the Amarna period that the Shaduf or pale and bucket lever was introduced (Figs 3.13, 14 & 15). This labour intensive tool made by attaching the bucket and its rope to one arm of a balance and counter-balancing its weight by a fixed counterweight can lift containers of water up to one and a half meters. A shaduf worked by two men in alternate spells of one hour gives a discharge of 100 cubic meters in twelve hours (as estimated by Willcocks 1889). This amount can irrigate 0.3 of an acre of land. With needed repeated waterings this would irrigate about 4 acres during the summer. Manual or Shaduf

Fig. 3.12. Inspectors measuring the grain from the tomb of Menna, scribe of the fields of the lord of the two lands Tuthmosis IV, Dynasty XVIII.

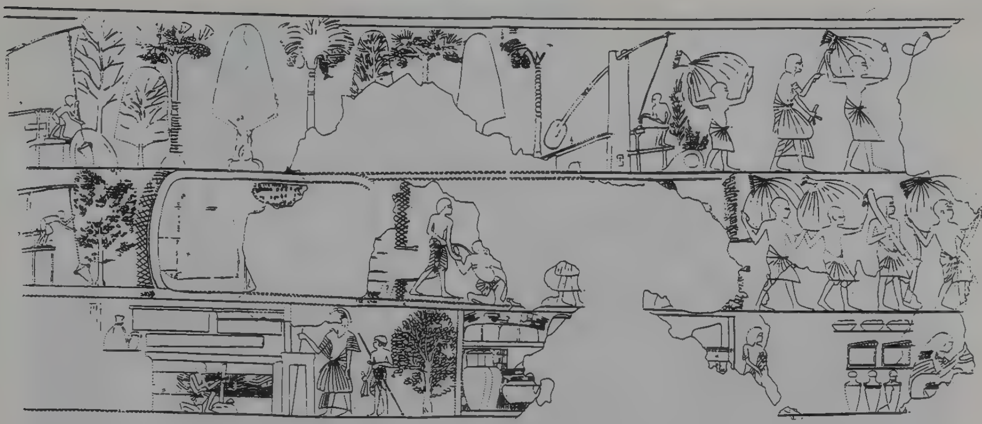

Fig. 3.13. Tomb of Nefer-Hotep at Thebes, inner room, north wall. Shadufs supplying water for a vineyard (after Davis N. de G. 1933).

Fig. 3.14. Man and shaduf from Samuel Manning 1876. The Land of the Pharaohs.

lifting, therefore, can only be used for irrigating gardens and small plots. The irrigation of large plots became possible with the introduction of the Archimedes spiral or the *Tanbur* and the waterwheel or *Saqia* which were introduced in Ptolemaic times.

The Archimedes spiral consists of a water-tight cylinder enclosing a chamber walled off by spiral divisions running from end to end placed in the water to be raised. The water, while occupying the lowest portion in each successive division of the spiral chamber, is lifted mechanically by the turning of the machine.

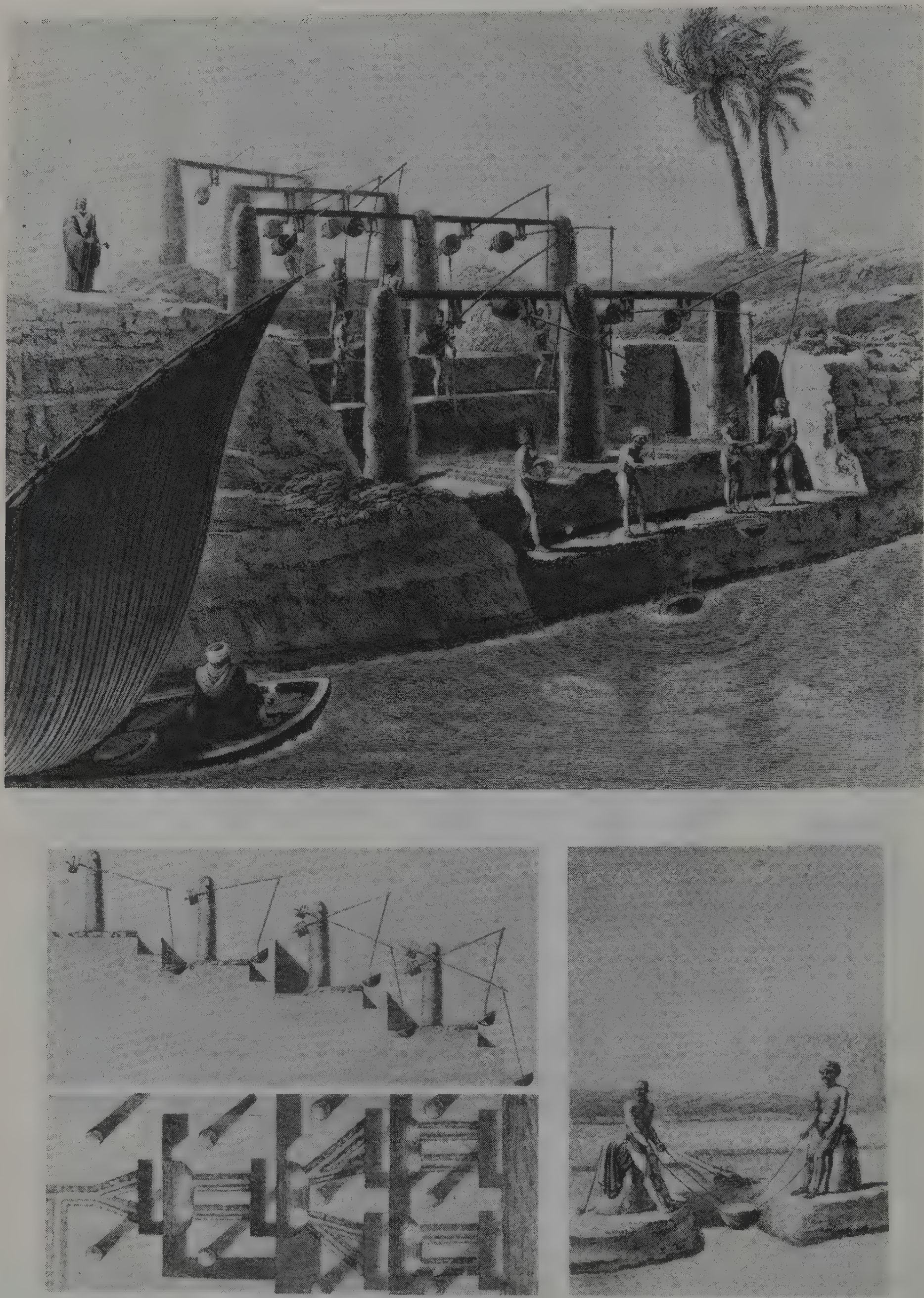

Fig. 3.15. Lifting water from the Nile by a series of shadufs from La Déscription de l'Egypte.

The waterwheel represents a great advancement in the art of water lifting (Figs 3.16 & 3.17). Here a row of pots is attached to the rim of a revolving wheel which is dipped in the irrigation canal. The wheel, upon being turned by beast, can lift the water nearly to its height which is

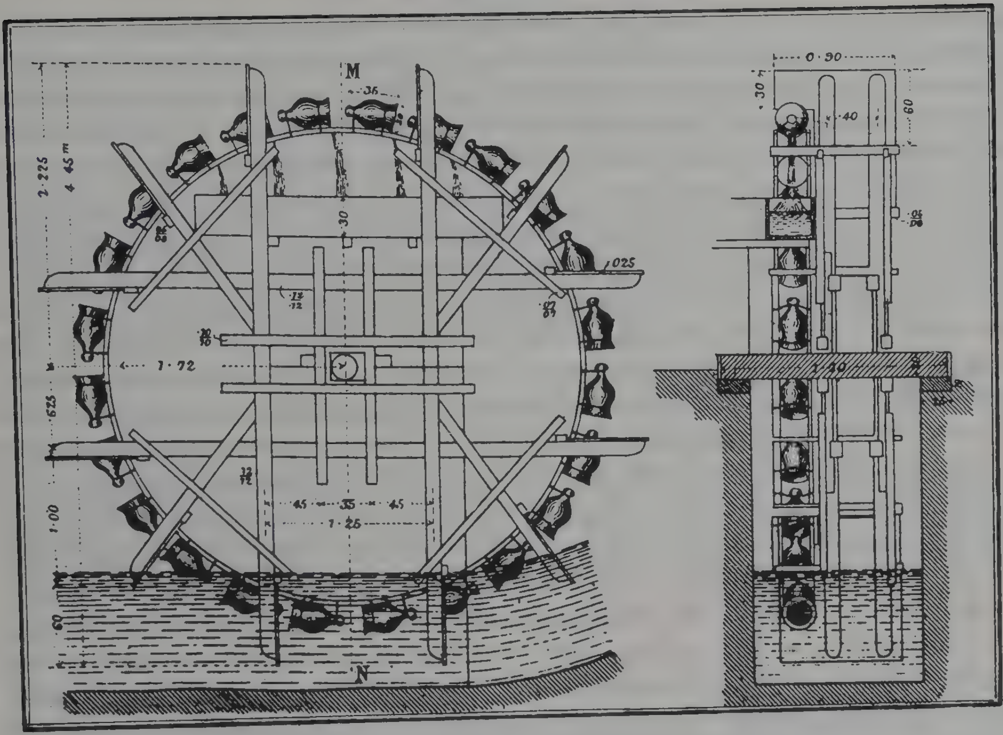

Fig. 3.16. Plan of waterwheel (Saqia) (after Willcocks and Craig 1913).

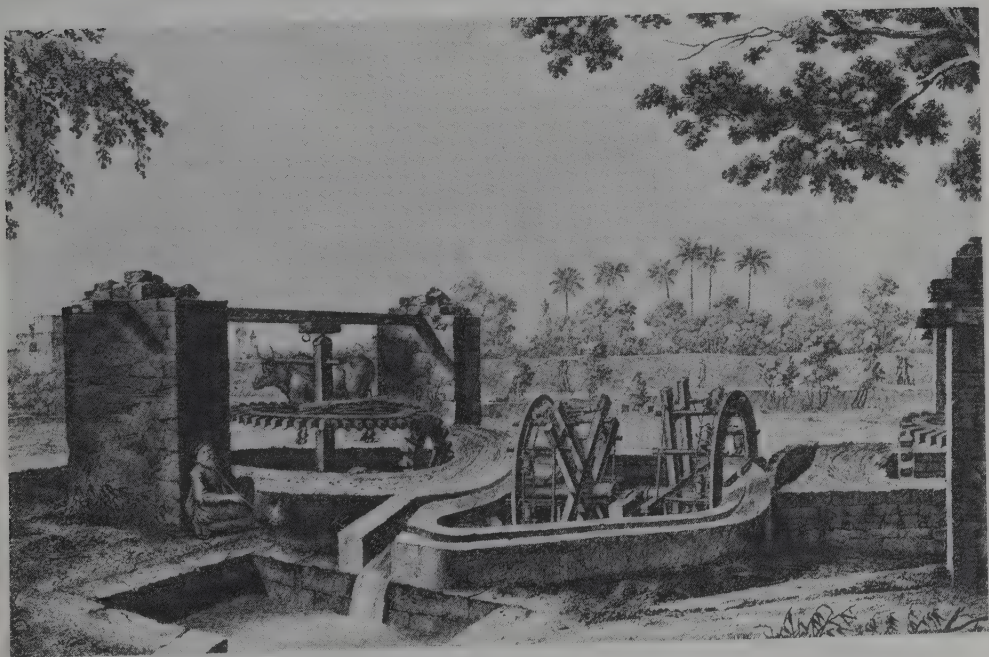

Fig. 3.17. Saqia from the Fayum from La Déscription de l'Egypte.

usually in the range of 3 to 6 meters. A saqia worked by two oxen in alternate spells of two hours for twelve hours can lift, from a depth of 4 meters, 285 cubic meters of water; this can irrigate 0.9 of an acre (as given in Willcocks 1889). This amounts to the irrigation of about twelve acres during the summer season. The spread of the waterwheel during Ptolemaic and Roman times led to the introduction of summer as well as flood crops and increased the wealth of Egypt.

The use of the waterwheel also enabled the Ptolemites to greatly expand the agricultural land of Egypt and reclaim the Fayum district which until then had formed a lake and an escape for high floods since Middle Kingdom times. They dried up the lake and made the Fayum into a province, giving it the name of the Arsinoite Nome, with Crocodilopolis, renamed Arsinoe in honor of the wife of Ptolemy II (285–246 B.C.), as its capital. The drying up of the lake from its previous level of 20 meters above sea level to about 2 meters below sea level occurred during the latter part of the reign of Ptolemy I (323–285 B.C.). The new level of water which the lake reached after it had dried up is surmised from the inferred level of water in an ancient saqia well described from the northeast of Birket Qarun (Fig. 3.18) by Caton Thompson & Gardner (1934). The date of the construction of this well was fixed on the basis of the presence of a coin of the early part of the reign of Ptolemy II. The level was marked on the masonry lining of the well by a layer of salt incrustation where the water seemed to have stood for a long time.

The great lowering of the lake level that took place during early Ptolemaic times could not have been caused by a fall in the level of the Nile, for we have the strongest evidence that the flow of the Nile was adequately high (section 6.2.6, Part II). It seems certain that the Ptolemaic rulers saw that there was no longer any necessity to use the Fayum depression as an escape for a large proportion of the flood waters of the river to protect the lands of lower Egypt and that, having recognized this, Ptolemy I conceived the idea of reclaiming a portion of the submerged area of the Fayum by lowering the water level of the lake. He did this by constructing a dike near Lahun to restrict and control the entry of Nile water into the channel leading to the depression.

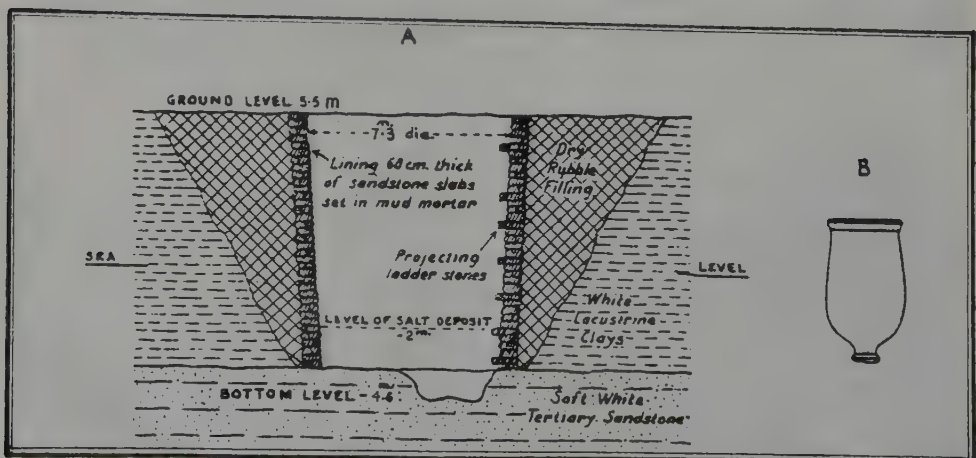

Fig. 3.18. A. Vertical section of Saqia well of the time of Ptolemy II, about 6 kilometers from the northeastern corner of Birket Qarun; B. one of the 15 earthenware jars found in the well (after Ball, J. 1939).

It is probable that Ptolemy I used the ancient embankment built by the Middle Kingdom king Amenemhat I which up to this day surrounds the entrance of the Hawara channel near Lahun (Fig. 3.19). The embankment was designed to close the gap of the Hawara channel between the two hills except for a single opening, near the site of the present Lahun regulator, which was furnished with a dam and weir to control the flow of water. The amount of water which was allowed to enter the depression at the Lahun weir was controlled so as to keep the level of the lake at 2 meters below sea level; the remains of Ptolemaic towns lie at or about the present sea level (Fig. 3.19). No Ptolemaic settlement has been discovered at levels below the minus one meter (below sea level) contour. This may be taken as further evidence that the level of the lake stood at or about minus 2 meters at least to the end of Ptolemaic times.

The canal system which channeled the Nile water into the circular depression of the Fayum was unique in Egypt. Unlike the system of canalization used in the valley and delta, the Fayum system was made up of a radial network of relatively high-gradient canals.

The enormous Fayum reclamation project devised by the Ptolemaic engineers added close to 325,000 acres of new and fertile arable land to Egypt. This together with the wide-spread use of the waterwheel increased the wealth of Egypt manyfold and brought its population to an estimated 4.9 million souls, the maximum ever recorded during the long history of Egypt before the great population explosion of the latter part of the nineteenth century.

Fig. 3.19. Map of Fayum showing sites of Ptolemaic towns (redrawn from Ball 1939).

The increased wealth was also due to the efficient although repressive administration in Ptolemaic times. Papyri from this period speak of a hierarchy of officials who supervised irrigation, surveyed the lands and overlooked the repairing of the dikes, the dredging of the canals and the clearing of the weirs. Much of this work was carried out by unpaid workers (corvée) who were recruited between the months of April and June as part of the tax system. The elaborate network of extension services in the Fayum region is on record (Lewis 1983). This picture should not lead us to believe that the Egyptian farmer had any share in this wealth. He remained, as his ancestors since at least New Kingdom times, exploited and in abject poverty. Nothing better expresses his case than the ancient Egyptian saying that the farmer's "reckoning lasts until eternity" (Ermann, Literatur der Ägypter).

3.2. Land Use in Ancient and Medieval Egypt

> "We are told that Napoleon in Egypt laid great stress on the proper maintenance of the irrigation works, saying at one point, 'In no country has the government so much influence over the public prosperity. The government has no influence over the rain or snow that falls in Beauce or Brie. But in Egypt the government has direct influence on the extent of the inundation it directs. That is what made the difference between the Egypt administered by the Prolemies and the Egypt already decaying under the Romans and finally ruined under the Turks'". F. Charles-Roux (1937). *Bonaparte, Governor of Egypt*, London: 113.

The potentially cultivable lands of Egypt included all the lands which were inundated annually by the river. Their area, therefore, was a function of the flood volume. At times of reasonably good floods these lands amounted to about 2.9 million hectars or 7 million feddans (1 fedddan=1.038 acres=4200.8 square meters). The area of the potentially cultivable floodplain of upper Egypt remained basically constant at about 800,000 hectars (2 million feddans). Expansion in these lands was limited. It was only after the introduction of lift irrigation, which allowed summer cropping on the levees, that the arable land increased by about between 10 to 15 percent. The area of the delta flood plain, on the other hand, differed from one time to the other depending on how much of it was drained and reclaimed. It was settled from the earliest of times when most of its land was used for pasture. It represented a frontier land for reclamation. Its cultivable and pasture land increased from 800,000 hectars in Predynastic times to 1,000,000 hectars in 1800 B.C. to ca. 1,300,000 hectars in the Ramesside period (1250 B.C.) to ca. 1,600,000 hectars during the Ptolemaic period (150 B.C.). Until New Kingdom times the estates of the delta were dispersed, forming a large-meshed network of domains offering great opportunities for reclamation and the winning of new cultivable land by the building of dikes and canals and the draining of flooded ground. The frontier spirit can be surmised from texts which praise the delta nomarchs for their work in "founding" villages and establishing estates. The royal chief steward of Ramses III (about 1170 B.C.) created an estate for the growing of fruit on the "Western River" (Canopic arm of the delta) from newly reclaimed land that had formerly been *birket* or flood-land and donated it as the estate of No-amun to Amun of Thebes (Kees 1961: 189).

The Fayum depression, which was under water for most of early historic time, was another frontier which added to the agricultural land of Egypt about 130,000 hectars after it had been dried up during the Ptolemaic period.

The total cultivable (and pasture) lands of Egypt increased from ca. 1,600,000 hectars (3.8 million feddans) in Predynastic time, to ca. 1,700,000 hectars (4,080,000 feddans) in

2500 B.C., to ca. 1,800,000 hectars (4,300,000 feddans) in 1800 B.C., to ca. 2,200,000 hectars (5,280,000 feddans) in 1250 B.C., to ca. 2,700,300 hectars (6,550,000 feddans) in 150 B.C. (Butzer 1976).

In the process of converting the land of the flood plains of Egypt to agricultural land, the virgin pasture lands, hunting thickets and fishing pools of the valley gradually disappeared. The conversion and upkeep of the fertile agricultural land thus gained, involved a great amount of timely work to clear, dredge and maintain the complex system of canals and dikes. This required a competent and effective authority on the local and central levels. Periods of stability and power were periods of innovation, extended land use, reclamation and repopulation. During periods of low floods and/or bad government a large portion of the land was left fallow. We shall see that during periods of decline the lands of Egypt were reduced to one sixth of what they used to be during periods of stability.

From ancient Egyptian times the lands of Egypt were recorded for tax purposes in registers of area and ownership. They were also registered according to their yield. A system of classification of the land was in effect from the earliest of times. This classification can be surmised from the Wilbour Papyrus (Gardiner 1948) which is the record of a survey of lands belonging to temples and various other public institutions in a stretch of the Nile Valley from the vicinity of Minia to the Fayum. The survey was made in the fourth year of the reign of Ramses V (ca. 1150 B.C); it began before the fifteenth of the Second Month of Inundation and continued until the first of the Third Month. This corresponds approximately to July 23–August 8 in the Julian calendar, or 9 days earlier in the Gregorian, the season which preceded the opening of the basin canals after which evidently no assessment of crops in the fields could be made. Although it is difficult to interpret the exact meaning of the terms used in this document, it is certain that the lands were classified according to their productivity. The category of low lands named "*p't*" constituted the fertile basin lands which gave a single winter crop. They were divided into lands which were annually inundated even during years of low floods (the so-called virgin lands or "*nḫb*") and lands which were not reached by an average flood (the so-called "*tni*") and which then had to be irrigated artificially. There was also the category of lands which stood higher than the surrounding lands (the so-called "*q³t*") and gave multiple crops. These were prized lands which were owned by the Pharaoh or the privileged class. They needed intensive work and were used for the cultivation of exotic and expensive crops or trees.

A similar system of classification was in effect in Egypt until the beginning of the nineteenth century. The following classification is given in the *Déscription de l'Egypte*: (1) Lands used for the cultivation of winter crops (the main harvest, planted after the inundation); these were called bayadi or basin lands when they were inundated (*?p't* lands of Ancient Egypt) and Sitawi when they were not reached by the inundation but were irrigated artificially (?"*tni*"). (2) Lands used also for summer crops (planted after the harvest of winter crops); these were called *Seifi* or *Qaizi* lands. (3) Lands used for flood crops (grown during the inundation in areas not flooded or protected from flooding); these were called damiri when they were low and nabari when they were high, requiring artificial watering (?"*q³t*" lands of Ancient Egypt).

There are many documents which shed light on the way land was used and farms were managed in ancient and Graeco-Roman Egypt. Surviving sale documents of farm land in ancient Egypt show that part of the land was owned by private individuals in all periods of ancient Egyptian history (Baer 1962). Although the king was theoretically the sole owner of the land,

he possessed the power of bestowing property as gifts to members of his family or to people whom he regarded as their equals because of their position in society (Kees 1961). All such gifts, therefore, were in principle royal prerogatives transferred to particular persons and at no time was the right of the king to take back his property contested. In practice, however, large estates were held by those "honored before the great god" and were inherited by their descendants either by making sure that the office, which usually came with the acquired property, went to the son or by endowing the property to the cult of the deceased. According to the rules of this cult the eldest son, as heir and new head of the family, had the duty to call upon his brothers and sisters to become members of the cult in return for a share in the produce from the land belonging to the endowment. Obviously the king still held in his hands the power to cancel or reverse any of these transactions (Kees 1961).

Starting from the time of the accession of Dynasty V gifts of land to temples became considerable. At first the endowments were provided from the wide expanses of the delta. Then they came from all nomes. In the time of the New Kingdom the state temple of Amen Re was the recipient of very rich gifts (Kees 1961). By that time land appropriated by the temples became very large representing a sizeable portion of the land of Egypt. This situation continued until the time of the Roman Emperor Augustus when these lands were severely reduced and taken away from the custody of the priests. Papyrus Harris (Breasted 1962) gives the area of the temple lands during the reign of Ramses III as 1,070,419 arouras (or 713,600 feddans). These lands are considered by most authors as the whole extent of the property owned by the temple during the reign of that king. Other authors consider the lands cited in the papyrus as representing only the new lands added by the king to the already existing endowments of the temple.

Apart from the temple lands most of the land belonged either to the state or to the king or the Emperor or the ruler depending on the times. Members of the court and moneyed classes also found the acquisition of landed estates profitable. With such a structure the amount of land available for sale to private individuals was very small.

Throughout the history of ancient and medieval Egypt there were continuous and far-reaching changes in the ownership of private property and the size of the endowments as a result of changes in government or the indiscriminate use of the right of the ruler to withdraw the right of ownership. This, however, did not change the pattern of land ownership until the middle of the nineteenth century. Until that time most of the land was owned by the state and was cultivated by a system of sharecropping whereby the land was periodically redistributed among the farmers. This system of periodic redistribution of land caused little friction for there were almost always fewer farmers than the quantity of available cultivable land. The scarcity of manpower was due not only to poor health and high rates of infant mortality but also to the evasion of many farmers to work on the land because of excessive taxation that was required to be paid in both kind and human labor. Each village was collectively responsible for meeting tax levies and supplying an annual quota of men for the work corvées. This collective responsibility for taxes, debts and work amounted to a system of serfdom which tied the peasant to the land; the peasant was not allowed to leave his village under any circumstances. Until the coming of the agricultural revolution of the nineteenth century the major limiting factor of Egypt's agricultural development was the lack of manpower; the ratio of land to rural inhabitants remained constant for a long time. It was only between 1855 and 1858 A.D. that new laws were enacted introducing the principles of private property and the laws of Moslem inheritance to the Egyptian countryside. Any peasant who could demonstrate that he had continuously tilled a plot of land

for 5 years and had paid taxes on it could gain title to it and cede it to his heirs. In 1855 A.D. only about one seventh of Egypt's cultivated land was under private ownership. The bulk was owned by the state where farmers lived on these lands as serfs. By the end of the nineteenth century most of Egyptian agricultural land, which became privately owned to the farmers some 40 years earlier, became in the hands of a few; close to 42.5 percent of the land was in the hands of 11,000 owners representing less than 1.7 percent of the number of total owners. Most, if not all, these owners were absentee landlords (Waterbury 1978).

Most surviving contracts of the sale of land in ancient Egypt clearly point to the fact that the land was in the hands of landlords who had no intention of cultivating it themselves; the bulk of the land in ancient, as in modern Egypt, was not owned by the actual cultivators who, in most cases, could hardly have had the means to purchase land. The prices quoted in the documents of the sale of land in ancient Egypt are very low; in one document (Baer 1962) three arouras (about two feddans) were sold for the price of one cow. Since the land was purchased as an investment by people who would be leasing it to tenants, the price was determined by the return which an investor in farm land expected. The land was usually leased for a portion of the crop produced. The price of farm land, therefore, was determined by the value of that portion of the crop, or the rent, which the owner would obtain. Since the usual return on capital in ancient Egypt was between 17 and 25 percent and since the rent was in the range of one half of the crop, the price of land was twice to three times the value of the total crop of one year. In the Wilbour Papyrus, written during the Ramesside period (Gardiner 1948), a payment of 50 percent of the crop per aroura is given as rental money for the temple lands (with which this papyrus is primarily concerned) in a plausible interpretation of the text and as tax money in another interpretation.

After paying for the rent, the tenant had to set aside part of the crop for seed stock and taxes. The seed portion usually represented about 10 percent of the crop; an aroura of land, which ordinarily gave ten har (the har equals an artaba or 50 kilograms) of grain, required one har of seed.[(2)] The portion deducted for taxes, which were paid by the landlord, varied from year to year. For a long time the tax was variable and levied according to the flood level. It used to represent about 10 percent of the crop; but starting from the Ramesside period the tax became fixed irrespective of the flood level or the productivity of the land. The introduction of a fixed harvest tax made it all-important for the tenant to work hard if he wanted to keep a portion of the crop for himself. This must have produced a lot of competition and it is, therefore, not by chance that in the New Kingdom times the farmer was urged not to infringe on the rights of his neighbors while at work. The sins from which the judge in the other world had to absolve the dead before they could gain salvation included (as the one hundred and twenty fifth chapter of the Book of the Dead enumerates): lessening of the arable area, falsifying the boundaries of the land,

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[(2)] An aroura is a land measure of 100x100 cubits or 2750 square meters, approximately two thirds of an acre. The har is a unit of dry measure used for grain and other produce in New Kingdom times which is here taken to be equal to one third of a modern ardeb or one sixth of a bushel or one and one third of a gallon or ca. 50 kilograms. It is equal to the artaba which became the principal unit of dry measure in Graeco-Roman Egypt.

Units of measure have changed considerably with time. As an example, the ardeb, a unit of dry measure which is still in use in Egypt varied from 0.125 to 7.5 bushels. At present, it is one half bushel or 4 gallons or 150 kilograms. The values of the dry measures used in ancient Egypt make the productivity of the land in ancient Egypt similar to that of nineteenth century Egypt. This is a reasonable assumption.

"damming up the water in his time", and the selfish infringement of water-rights and land-rights to the injury of a neighbor (Kees 1961). What remained for the farmer after the payment of the tax was, on the average and in the best of times, about three hars per aroura (or 150 kilograms). Ordinarily the tax did not exceed 10 percent of the crop.

The land which was available for each head in ancient Egypt may be gleaned from Papyrus Harris (Breasterd 1962), written during the reign of Ramses III, which gives the number of heads living on the 1.1 million arouras of temple lands as 107,615, or approximately 10 arouras per head. These temple lands represent about one tenth of the modern lands of Egypt, and they certainly represented a much larger proportion of the arable land of ancient Egypt. With such a large sample at hand, it can be safely said that the ratio of heads to arouras in ancient Egypt, as a whole, was close to that on these temple lands. Most authorities interpret the figure given in the Papyrus under "heads" as listing only men; hence the actual number of people living on these lands must have been in the range of 500,000 to include wives and children. This would mean that each individual on the temple domains was living on two arouras on the average.

Two arouras would give the individual after paying rent, taxes and seed stock about 300 kilograms of grain per year assuming that the entire land was used to raise grain. In practice, this was not the case; some land was used to grow flax and other non-edible products and some was used for vegetables and other low-calorie foods. Assuming that these represented 25 percent of the total arable land area of ancient Egypt, it follows that the individual's share of grain was about 225 kilograms per year, that is less than two thirds of a kilogram per day. The caloric value of the digestible components of this quantity would be about 2200 calories per day. Today this number of calories would be considered an absolute minimum for the continued good health of a man weighing 50 kilograms and engaged in the strenuous physical activity of farm labor. It is interesting to note that in Roman times hired hands on the farm were paid their wages in the form of two loaves of bread a day or roughly half a kilogram per person (Baer 1962).

The situation became considerably less favorable to the tenant when Egypt started to direct its grain production for export under Psammetik (Dynasty XXVI). For centuries thereafter crops grown in Egypt were vital for feeding the Mediterranean area. This made Egypt henceforward the object of conquest by powerful nations. The Greeks took control of Egypt in 323 B.C., colonized the country and ran it efficiently though ruthlessly. The Egyptian peasant was exploited and there are records of persistent strikes and civil unrest throughout the period, especially after 150 B.C. when the system began to collapse. Under the Romans who took control in 30 B.C. organization and efficiency were restored, but the new system brought a new dimension of ruthlessness. The Ptolemites had at least lived in Egypt, and the money they exacted had stayed in the country. The Romans, on the other hand, were absentee landlords who milked Egypt mercilessly.

It is interesting to note that this exploitative pattern of land use, owner–tenant relationships and property rights continued with little change for several millenia, in fact well into the nineteenth century. This speaks once again for the staunch conservatism of Egyptian society under the system of basin irrigation.

3.3. Crops of the Basin Irrigation System

The main crops of the system of basin irrigation in ancient Egypt were the winter crops of cereals and flax. Both had a growing season which fitted in with the climatic cycle which followed the arrival of the flood and the sowing of the basins. In addition to the cereals (mainly barley and wheat) and flax, ancient Egyptian agriculture included the cultivation of beans, lentils and onions. Large areas were left as pasture land and these were later cultivated with *bersim* (Egyptian clover) which seems to have been introduced during the Roman occupation. Since then *bersim* has become an important crop; by the close of the eighteenth century it accounted for one fourth of the total cultivation of the delta and one sixth of that of Upper Egypt (Hamdan 1961). These extensive tracts of land were used for the raising of draft animals that contributed to agriculture and the raising of the core crop of cereals. Unlike other Middle Eastern countries, animal husbandry did not play a significant role as a source of food or revenue for Egypt.

It is possible that more than half the arable land was used to grow cereals, chiefly barley, emmer and winter wheat. Durah (*Sorghum vulgare*) was unknown. The six-headed barley was the chief cereal grown in Old and Middle Kingdom times; it was classified by variety into lower Egyptian and upper Egyptian barley. By the time of the New Kingdom, however, emmer became the chief cereal; it took first place among the grain returns listed in the Wilbour Papyrus (Dynasty XX). From that time and until the Late Period it was the grain chiefly used in Egypt for bread as reported by Herodotus. During the Ptolemaic period winter wheat was introduced and formed a large part of the winter grain crop which had become the chief export of Egypt.

Emmer and barley were amongst the oldest grains used in Egypt. They were grown in the Neolithic settlements of the Fayum (ca. 5200 B.C.) and the Predynastic villages of Nagada I (ca. 4000 B.C.). Barley husks were found in the intestines of Predynastic mummies. Kernels of wheat were uncovered in Neolithic storage pits lined with basketry dug at the edge of the desert. Tomb paintings give precise details of how the grain was grown (Fig. 3.20). After the seed was scattered over the Nile mud, sheep driven across the field trampled the grain into the ground. When the crop ripened, men with sickles lopped off the grain heads and hauled them in baskets and nets to the threshing floor. Oxen or donkeys, prodded by shouts and sticks, threshed the grain. Then winnowers tossed the grain with wooden scoops to separate kernel from chaff.

Flax was the foundation of the famous ancient Egyptian linen industry and it also contributed to the supply of oil. Its harvesting provided a favorable subject for the reliefs of the tombs of the Old Kingdom. Flax was also found in Predynastic sites. Among the vegetables of ancient Egypt onions and leeks served as food for the common people, as is the case today; dill was used as a medicinal herb and for mummification; lettuce was grown in beds and was considered an aphrodisiac (Kees 1961). Of the leguminous plants lentils, peas and beans were popular, as they are today. Lentils and peas were found in Neolithic and Predynastic sites but beans were introduced at a considerably later time (? Dynasty XII) from the Levant (Hopf 1986).

Oil-producing crops formed an important part of Egyptian agriculture. The oil produced was used in large quantities in food, ointments, cosmetics, medicines and for lamps. Oil was customarily used as payment in kind to workmen employed by the state. The commonest oil was obtained from the castor-oil plant and from flax. From New Kingdom times, sesame was cultivated for its oil which, in Ptolemaic times, was the most highly valued in the oil monopoly.

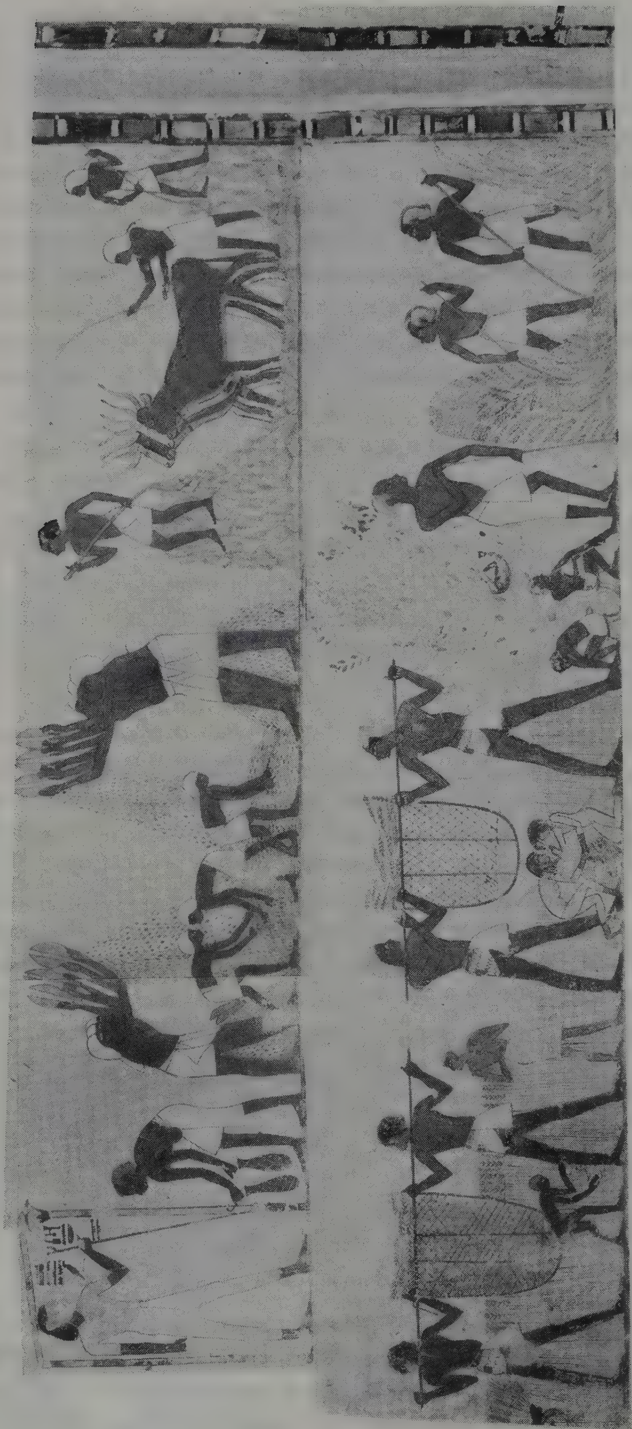

Fig. 3.20. Grain growing in Ancient Egypt. Bottom, men with sickles lopping off the grain heads and hauling them in baskets and nets to the threshing floor; Top, oxen threshing the grain and men with pitchforks adding the heads underfoot from stacks around the floor.

In addition to the core of winter crops, there was always a group of non-winter crops which were raised in areas where water was available all year round. From Predynastic times these isolated and small areas, which stood like islands in the landscape of Egypt, made the richest nomes. Perhaps the earliest of the perennially irrigated lands were those which lay next to the ponds and lakes which formed at the lower tracts of the flood plain after the flood water had receded. In these areas the water, which was usually available many months after the flood had gone, was lifted in buckets and carried to nearby fields. The other perennially irrigated lands included the high lands along the embankments of the extant and the abandoned channels of the river (the so-called *nabari* lands). These were not inundated except during a high flood. They were watered by lifting from wells which tapped the shallow and abundant groundwater reservoir. The effort must have been great but the reward was greater material wealth. These "hanging" fields formed some 12 percent of the lands of upper Egypt and 25 percent of the lands of the delta at the beginning of the nineteenth century when the French Expedition completed the survey of the lands of Egypt.

Because of the expense involved in the lifting of water the crops had to be of some cash value. In ancient Egypt the areas were reserved for horticulture. Fruit trees and vine were among the most cherished. Among the trees grown were the date palm, fig tree, Christ's thorn tree (*Zizyphus spina christi*, in Arabic nab'a), sycamore, acacia, persea tree (*Mimusops schimperi*, in Arabic Lebekh), pomegranates, willows and many others. The date palm, in particular, was considered one of the most useful trees which enhanced the value of the land. As early as the Old Kingdom the state took advantage of this and levied special taxes on these lands. In orchards, vines were the object of special attention. The use of the hieroglyphic sign for vines in the writing of the words 'orchard' and 'gardner' shows that the planting and care of vines was a gardner's most important task (Kees 1961). The best known centers for cultivation of vine were the coastal areas of the delta, especially around Pelusium and Tanis in the northeast, and present-day Mareotis in the northwest where, according to ancient opinion, the best Egyptian wine was produced. Wines from the estates "on the western river", or the Canopic arm of the delta, were also highly thought of and were found in the cellars of the palace of Amenophis III at Thebes and later at Amarna (Fig. 3.21). Egyptian vines yielded grapes suitable for more than five kinds of wine. Red wine seemed to have been favored in early periods, white in later dynasties. Most vineyards lay within walled estates, with the plants trained to trellises; gardners watered them from earthen jugs and shooed away birds with slingshots and shouts. At harvest time, pickers carried the bunches of grapes to crushing vats, where barefoot workers stomped out the juice. The juice was then fermented in open urns; finished wine went into jars. Markings put on the jars gave as much information as modern labels, often more. They bore the name of the estate, its location, the vineyard, the name of the vintner, the date and an assessment of the quality — "good", "twice good", "three times good", "genuine", "sweet". One from an Amarna tomb was downgraded as "for merrymaking". 1344 B.C. seemed to have been a great vintage year (Butzer 1978).

The *nabari* lands were also used for growing numerous other valuable crops which were introduced at considerably later times. These included sugarcane, rice, indigo, saffron, tobacco and cotton. By far the most important of these for medieval Egypt were sugarcane and rice which were introduced by the Arabs in the Middle Ages. During the twelfth and thirteenth centuries Egypt was an important exporter of sugarcane which was cultivated mainly in middle Egypt. Sugarcane was an expensive crop to raise; it required lavish waterings, hard ploughing and good drainage. It must have fetched a great price at that time. Rice was introduced immediately after

Fig. 3.21. An orchard in Amarna. Pickers carrying the bunches of grapes to crushing vats, where bare foot workers are stomping out the juice.

the Arab conquest in the seventh century either from Syria or ?India. Because of its need for excessive watering it was cultivated mainly around the two distributary mouths of the delta and in the Fayum province where water could be easily lifted. Cotton was grown in the valley and the delta but on a minimal scale. It did not assume importance until the nineteenth century.

3.4. The Population of Ancient and Medieval Egypt

The question of how many people lived in the land of Egypt prior to the introduction of reliable methods of census in the early nineteenth century has been the subject of controversy. The first reliable census in modern times was made in 1801 A.D. by Jomard of the French Expedition who estimated the population at 2,488,950. This was followed by another census in 1821 in which the population was given at 2,536,400 based on the tax levied on the cultivated land which amounted to 1,956,640 feddans. According to an 1845 census the population of Egypt increased to 4,476,440 and the land to 3,856,226 feddans.

The number of people who inhabited Egypt prior to 1800 A.D. and in earlier times is difficult to estimate with any certainty. Many lines of evidence have been used to estimate the population of Egypt from Predynastic times to the early nineteenth century. In addition to using the estimates given in the works of the classical writers, the number of people who lived in Egypt has been inferred from the size and use of land holdings, the density of centers of population and poll and land tax assessments. Estimates given by the classical writers are questionable at best. Diodorus (first century B.C.) and Josephus (first century A.D.) who lived only 100 years apart gave two very different estimates of the population of Egypt. Diodorus claimed that Egypt's population was small and did not exceed 2 million. Josephus, on the other hand, claimed that Egypt was a populous country supporting a population of 7.5 million. He came to this figure by dividing the total amount of poll tax collected from Egypt (as mentioned by Herod Agrippa) by what he assumed to be the per capita tax. Since the poll tax in Herod's time varied from person to person and from profession to profession, it is clear that the total sum of tax cannot give the actual number of tax payers when divided by one figure. The impression given by Josephus that Egypt was a populous country survived him and the figure that he gave for the number of people living in Egypt was repeated time and again in the literature up to relatively recent time.

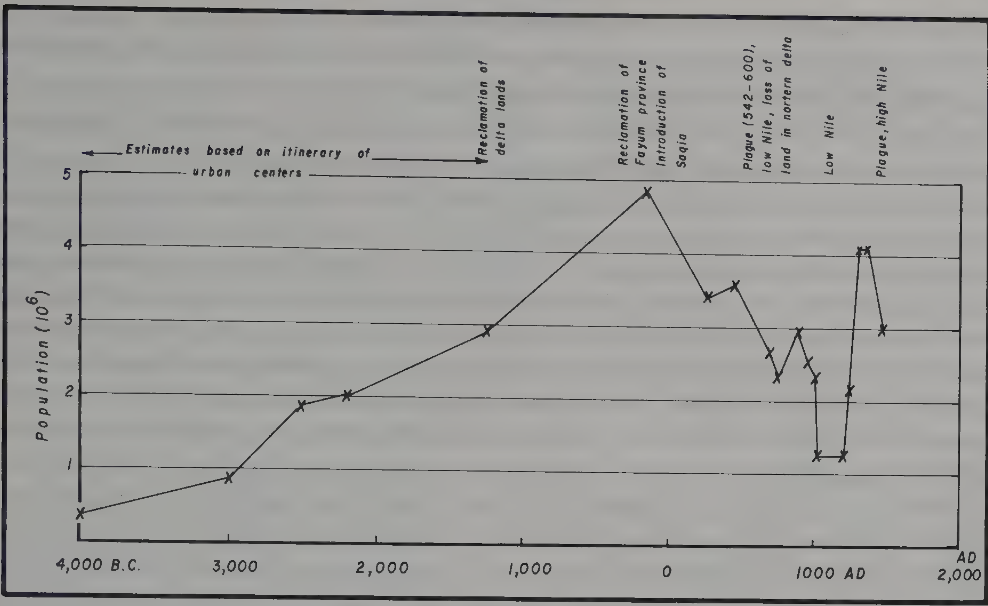

Fig. 3.22. The estimated population of Egypt from 4000 B.C. to 1480 A.D.

It is difficult to believe that Egypt could have supported that number of people in ancient times. Except for a very short period of time there was not enough land to feed that number of people. In view of the fact that foreign trade played a minor role in providing Egypt with grain during most of its ancient history, Egypt had to depend on its own land to produce food for the people who lived on it. That amount of land determined the maximum number of people who could live on it (or its carrying capacity). There are at least two ways to determine that capacity. One way, which is purely theoretical, is to estimate the number of persons who can be sustained on the amount of protein that the yield of the natural land (without the addition of any fertilizers) can produce. Jenny (as quoted in Baer 1962) estimates that 1.75 persons can survive on the amount of protein that can be extracted from the yield of one acre of the land of Egypt with its inherent nitrogen content. Assuming that part of the land was used for other essential crops and that part of the product was wasted, the carrying capacity of the land of Egypt must have been in the range of one person per acre or some 5 million souls in the best of times.

The carrying capacity of the land of Egypt can also be determined by the amount of grain it can produce. The area of land that was reserved for grain production varied from time to time. The crop yields given in the Wilbour papyrus (Gardiner 1948) show that during the Ramesside period (and probably during most of ancient Egyptian time) close to three quarters of the land was reserved for cereals and the rest for flax and other low calorie products. The papyrus also shows that the yield of cereals per unit of land was close to that of nineteeenth century Egypt (i.e. 750 kilograms per feddan). This brings the amount of cereal that was available for human consumption from each feddan of the entire land of Egypt to 560 kilograms. Assuming that one third of this is wasted or reserved for seed stock, it follows that the feddan could not have supported more than 2 persons (with a per capita consumption of bread equalling that of modern rural Egyptians, i.e. about 180 kilograms). Since Egypt never had more than 3.5 million feddans

under cultivation except in the Late Period and in Hellenic and Roman times (*vide infra*), it would have been impossible for the land to support a population of 7 million except during these times. However, during these times Egypt exported at least half of its grain to Rome. The remaining grain could not have supported a population of the size mentioned by Josephus.

Estimates of the population of Egypt during Predynastic and Dynastic times are made by Butzer (1976) who draws demographic inferences from the history of land use and also from the size of the known settlements of Dynastic Egypt. He makes an inventory of these settlements and lists some of their attributes in order to classify them according to their size into cities, large centers, small centers or large villages. Among the attributes he uses for rating the different sites are whether the settlement was a nome capital and the seat of a mayorship or whether it had tombs of nobility or royalty, villas, estates, suburbs, fortress, temple or quarry. Notwithstanding the many assumptions underlying this approach Butzer is able to show that the Nile Valley was by no means uniformly settled in New Kingdom times. It was densely settled (as much as 5 per hectar) in the southernmost nome of Aswan, between Aswan and Qift (Land of the Bow) and in the northernmost nome of Memphis (The White Palace). The densities in other nomes are thought to have varied greatly, as low as 7.5 per hectar between Girga and Qaw, the Cobra nome and around el-Fashn, the Double Scepter nome. A median density for the entirety of Egypt is given as 1.32 per hectar. This pattern of population distribution is totally different from that of the nineteenth century A.D. when Girga province as well as the region of Cairo provided the major settlement concentrations.

Recognizing that the density of population per hectar has increased with time, Butzer gives the following estimates of the population at different periods (Butzer 1976).

Date B.C.	Arable land (10^3 hectar)	Population density (per hectar)	Total population (in millions)
4000	1600	0.25	0.4
3000	1500*	0.60	0.9
2500	1700	0.95	1.6
1800	1800	1.12	2.0
1250	2200	1.32	2.9
150	2730	1.80	4.9

*A decrease of 100,000 hectars due to the encroachment of the sea on the delta lands.

From the above table and Fig. 3.20, it is clear that the population of Egypt was at its highest during Ptolemaic time when it reached 4.9 million. At that time Egypt supplied not only its own population with grain but exported a large surplus to Rome and other cities. The increase in population during that period was due to the expansion of arable land by the addition of large areas of reclaimed land in both the delta region and the Fayum province, and also to the expansion of summer agriculture as a result of the introduction of the waterwheel. The earlier jump in population during New Kingdom times was also due to an increase in the arable land in the delta region. It is interesting to note here that the ratio of population to land decreased from 2.2 acres of land per person in 1800 B.C. to 1.4 acres of land per person in 1250 B.C. We have already seen that documents from the Ramesside period seem to indicate that the density of the

rural poulation was one person per two arouras. That would make the density per hectar about 1.8 persons rather than 1.32 as given by Butzer.

A steady decline in population took place from the end of the Ptolemaic period and through the Roman rule. The decline accelerated at the end of the third century A.D. during the rule of Diocletian when, under a newly introduced tax law, the farmer was overburdened. There was unrest and abandonment of farm land to the extent that some believe that the cultivated area dropped to almost one half its original size. Further decline took place during the latter part of the Byzantine period when Egypt was subjected to three great catastrophes namely, the great plague of 542–600 A.D., the low Nile during the same period and the submergence of the northeastern part of the delta by an advancing sea. At that time Egypt's population declined to less than one half the size of its population some 600 to 700 years earlier. Population estimates go as low as 2.4 million. Cultivated land shrank enormously to almost one half what it used to be during the Ptolemaic period (Russell 1966).

After the Arab conquest of Egypt in 640 A.D. the reasonably preserved record of land assessments offers a means of estimating the size of the cultivable area and the number of people who lived on it. When the Arabs entered Egypt they imposed a head tax of two dinars on non-Moslems. If we are to believe that the amount collected (12 million) was in dinars, as Tousson (1924) advocates, then the population of Egypt during the first years of the Arab conquest would have been about 30 million (assuming that each tax payer was heading a family of five). This seems to be a very high figure, and most authorities are of the opinion that the taxes, at least up to the mid-tenth century, were collected and reported in dirhems (one dinar=12 dirhems) rather than dinars (Russell 1966). If that was the case the population of Egypt would have been in the range of 2.5 million people. The poll tax remained in the range of 12 to 14 million dirhems during the caliphates of Omar and Uthman, but during Muawija's rule (661–680 A.D.) it decreased to less than one half that figure. This was probably due to the sharp decline in the number of non-Moslem tax payers who are estimated to have numbered 208,000, representing possibly a population of one million. The decline in the number of Jews and Christians living in Egypt from 2.5 million to one million within one generation assumes that a large number had only a nominal interest in religion, changing membership under little pressure or for sheer tax advantage. The number of churches of the period seems to have been in the range of 200, two thirds of which were concentrated in Alexandria and the three nomes of Oxyrhynchus, Aphroditopolis and Arsinoite, a concentration which suggests that large areas of Egypt must have been without pastors or strong religious affiliation. At that time Christian strife over heresy was particularly bitter, a condition which must have sapped the energies of the church and made it easier for people to leave a persecuted religion. From the time of Muawijah the Christian population seems to have maintained its size, but its decline started to accelerate under Harun Al-Rashid (Russell 1966).

For the period between the eighth and the eleventh centuries the population estimates are substantially low and fluctuate from 2.4 million in 730 A.D. to 1.6 million during the period of low Nile floods of the tenth and eleventh centuries. These estimates are based on the land tax (two dinars on each feddan), which was introduced at the beginning of the eighth century, the total of which varied from 4 million dinars during the rule of Hisham Ibn Abdel Malik (743 A.D.) to 4.3 million dinars during the time of Saladin (1189 A.D.). It fell to 3.2 million during the reign of el-Moez Ledin Illah (975 A.D.). The cultivated land, which had already

shrunk under the Romans decreased even further. It measured 2.4 million acres in the early ninth century and fell to 1.5 million acres during the reign of El Moez Ledin Illah. The population also fell and the number of heads became equal to the number of feddans cultivated.

Table showing land taxes in Egypt 8th to 12th centuries

Ruler and date	Tax amount (10^3 dinars)	Land (10^3 feddans)	Population (10^3)
Hisham Ibn Abdel Malik (743 A.D.)	4000	2000	2200
Al-Ma'mun (813–833 A.D.)	4257	2128	2365
Al-Motaz Billah (869 A.D.)	4800 (?)	2400	2640
El-Moez Ledin Illah (975 A.D.)	3200	1600	1760
Al-Mosstansir Billah (1090 A.D.)	3061	1530	1683
Saladin (1189 A.D.)	4277	2138	2351

4

PERENNIAL IRRIGATION

Basin irrigation was the most efficacious method of utilizing the waters of the Nile for the sparse population of ancient Egypt. It started with the small number of people who lived in ancient Egypt and continued to support them in wealth for as long as the basic infrastructure of dikes and canals was kept functioning. For 5000 years it was the only system known to the Egyptians. Supplemented by perennial irrigation of selected land areas, it gave Egypt a margin of wealth.

Whatever merits this system may have had were outweighed by the fact that it made only partial use of the land and left a large part of the water of the Nile to drain into the sea. It was unable to meet the needs of an expanding population. More importantly it left the population and land use at the mercy of the vagaries of the flood. The fact that the Nile was one of the most predictable rivers was not very relevant since the slightest deviation from the norm could cause untold damage for a society with an extensive infrastructure. We have already seen (section 6, Part II) that it was at times too low and at others too high. The former meant shrinkage of the cultivated area, sometimes to one half and even less. The aftermath was al-Shidda (crisis or famine), an all too recurrent dark spot in the history of fluvial Egypt, immortalized in the descriptions of the medieval Arab historians. Excessive floods were also equally disastrous. They swept away the *nabari* crops and left the basins a morass. The corollary was the plague, another stubborn feature in medieval Egypt. Within five centuries (fourteenth to the eighteenth) fifty plagues and epidemics ravaged Egypt, a rate of one every 11 years (Hamdan 1961).

In the early nineteenth century the system of basin irrigation began to change through an initiative from Mohamed Ali, who became the ruler of Egypt in 1805 shortly after the Napoleonic invasion. A large part of the delta lands was converted to perennial irrigation. The ambitious plans of Mohamed Ali to modernize Egypt and build its industry required a stronger economy, a fuller use of the land and the generation of foreign exchange by the marked expansion in the cultivation of cotton. Cotton is a summer crop which required water when the discharge of the Nile was at its lowest point. The year-round use of the land meant that water had to be available in the summer when the Nile was low.

The first attempt to achieve this goal started in 1820 when the floors of the flood canals of the delta were lowered to a considerable depth (6 meters plus) in order to reach the low summer levels of the Nile. To ensure that the summer (also called timely) water entered the canals and reached the cotton and other summer crops, the canals were run at a lesser slope than the land in order to allow the water to flow northward to the fields. These seifi (summer) canals proved a failure; the lifting of water from these canals proved costly and difficult. Worse still was the

enormous effort needed to clear the canals from the silt that accumulated in them after every flood. In 1825 the system of forcing the low water of the summer months to enter the canals by lowering their floors was abandoned and another attempt was made to raise the water level in the canals by building a series of regulators across them. This also proved highly uneconomical as the annual clearance of the silt accumulating on the upstream side of these regulators required an enormous labor force. The clearing of the canals was done by an army of forced (corvée) labor which in some years reached as many as 400,000 men. This proved expensive and impractical as it deprived the farms from the labor which was then needed for the newly introduced summer crops.

The system of corvée labor was old in Egypt. Historically it formed part of the tax levied on every farmer, whereby he would spend the summer months in preparing the land for the next season's agriculture. Under the system of basin irrigation in Egypt, corvée labor was tolerable and perhaps justifiable. The farmers had little to do during the working months of the corvée and the work itself, which included repairing the dikes and protecting the banks, was for the benefit of the entire community, including the farmers themselves. With the introduction of summer irrigation the farmers did not have the motive nor the time to spare for clearing the canals which were primarily used for the large estates. Abuses also crept into the system. What was historically intended as a community work turned into forced labor during the nineteenth century. Farmers were driven by force and without pay to build public and original works that had nothing to do with the maintenance work that was of benefit to the community. They were used to dig the Suez Canal and the Ibrahimiya summer Canal in upper Egypt — a canal which was constructed almost entirely for the benefit of the Khedivial private estates.

In order to avoid this massive task of canal clearing, Engineer Linant recommended to Mohamed Ali, the ruler of Egypt, the building of a barrage with sluices at the head of the delta to raise the water level of the river without accumulating silt. A barrage at the strategic position of the bifurcation of the distributaries of the delta was started in 1843. It had sluices to allow the silt to pass through during the height of the flood. The impounded raised water was to supply three arterial feeder canals (rayahs), each commanding a triangle of the delta (Fig. 3.23). Completed in 1861 the barrages functioned imperfectly until they were put in order in 1890 when they could hold up water 4 meters above its normal summer level. The full conversion of the delta to perennial irrigation was thus achieved. It was effected through a series of *seifi* (summer) canals which took off from the three rayahs rather than from the Nile branches. The rayahs were straight channels which had gentler slopes than the meandering river thus allowing the network of canals to spread all over the delta. The summer canals followed the old (and usually silted-up) channels and ran along the higher contours commanding the adjacent low-lying areas. From these, smaller feeder channels (misqas) took off.

The introduction of perennial irrigation to upper Egypt started from the north and proceeded southward. The Ibrahimiya canal (1873) was the first summer canal dug in middle Egypt. It ran on land one meter higher than its surroundings. Its water supplied the Khedivial plantations in middle Egypt.

4.1. Seasonal Storage Schemes

Until the end of the nineteenth century, perennial irrigation and the cultivation of summer crops depended on the use of the timely water carried by the river from

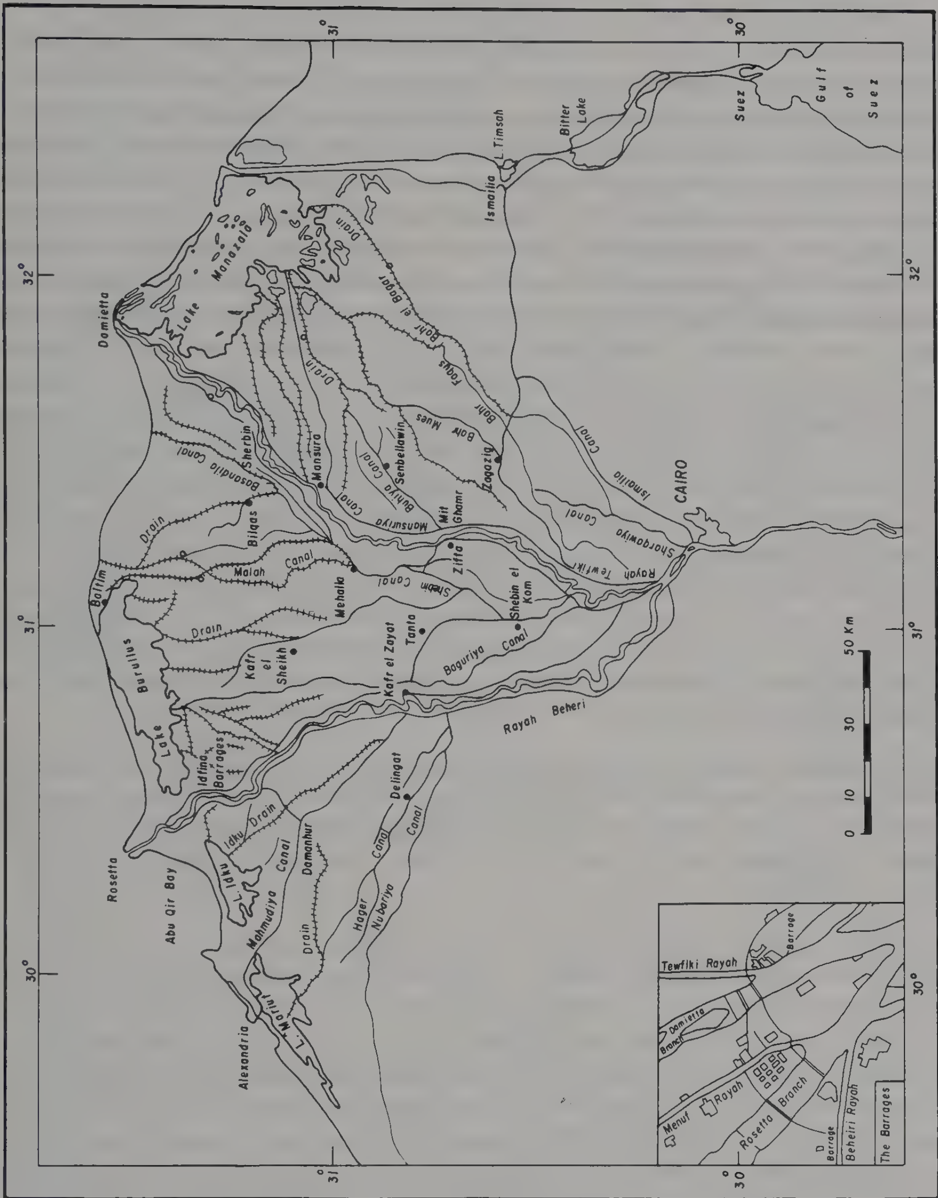

Fig. 3.23. Water delivery system in the delta region.

February to July. This amount represented only about 20 percent of the natural discharge of the river, or about an average of 15.4 billion cubic meters at Aswan. The expansion of perennial agriculture was limited by this amount of water which was made available through impoundment behind barrages.

A great stride in the realization of the system of perennial irrigation was taken at the beginning of the twentieth century by storing part of the excess waters of the flood season to be released and utilized during the following summer. This idea of seasonal storage was made possible by the damming of the river as it entered Egypt at Aswan. The Aswan dam was built in 1902. The two-kilometer-long dam was a pioneering engineering structure which was originally designed to store 3.6 billion cubic meters of water while allowing the silt carried by the river to pass through. It is pierced by 180 sluices for passing floods. During the height of the flood all the sluices were opened and the river discharges and its suspended load of silt were allowed to pass. When the turbid waters of the flood had passed the sluices were gradually closed and the reservoir was allowed to be filled. The Aswan Dam was a magnificent engineering accomplishmet which was suggested and designed by William Willcocks and agreed upon by an international commission. It is of interest to point out that in studying the project of the Aswan Dam the members of the commission concerned themselves with issues that went beyond the engineering and feasibility aspects of the project. They considered among other things the quality of the water and the measures that needed to be taken to "prevent the pollution of the reservoir" and the "deterioration of the summer waters". Of concern also was the consequent flooding of the Philae temple which caused one member of the commission to dissent and to propose reducing the capacity of the reservoir. The government of Egypt followed the advice of that dissenting voice and reduced the capacity of the reservoir from its original design of 3.6 billion cubic meters to one billion cubic meters (Willcocks 1904). That advice was neglected in later years when the dam was heightened and its capacity increased.

For the efficient use of the newly stored water of the Aswan Dam a series of barrages, like the one at the delta apex, were built: Assiut (1902), Zifta (1903) Esna (1909) and Naga Hammadi (1930). From each, carrier canals were dug. With increasing summer water requirements the Aswan Dam was heightened twice to bring its capacity to 2.5 billion cubic meters in 1912 and to 5.2 billion cubic meters in 1993.

The natural timely flow of the river at Aswan plus the supplementary 5.2 billion cubic meters stored at the Aswan Dam expanded summer agriculture and increased crop intensity to dimensions hitherto unknown in the history of Egypt. By the mid 1930's Egypt's 5,300,000 feddans of arable land had a cropping intensity of more than 156 percent. Population pressure and the need to expand summer agriculture required further supplies of timely water. For this purpose Egypt entered into negotiations with the Sudan to build the Gebel Aulia Dam. This dam, which lies some 40 kilometers upstream from Khartoum, was built in 1937 to store the White Nile waters in a reservoir of 3.5 billion cubic meters capacity. Because of the excessively high rate of evaporation the seasonal storage amounted to only one half of the dam's capacity. Egypt built the dam and compensated the Sudan for riverine areas flooded by the reservoir. The new supply of timely water brought the cropping intensity of the lands of Egypt close to 170 percent. It may be of interest to point out here that about 700,000 feddans were intentionally not converted to perennial irrigation in upper Egypt and were left under basin irrigation to take the excess of the waters of the flood during its height.

Two thirds of the timely water is ordinarily used in the delta region (Fig. 3.23) and is allowed to flow in the two delta distributaries, the Rayahs and the canals in the following percentages: Damietta and Rosetta distributaries (23.5 and 14.5 respectively), Beheiri, Menoufi and Tewfiki rayahs (17.5, 16.5 and 12 respectively), the Ismailia Canal (8) and other canals (8). In upper Egypt well over 50 percent of the remaining water is allowed to pass through the Ibrahimiya Canal which supplies the provinces of middle Egypt.

The perrenial irrigation system put an end to the inundation of the fields. Instead of one copious watering as was the case in the basin irrigation system, many waterings throughout the year are now applied at intervals. The system also confined the river to its channel and increased the danger of high floods thus reversing a situation that prevailed under basin irrigation when high floods did not adversely affect the basins which were naturally submerged and affected only the higher (*nabari*) lands. Under the perennial irrigation system, on the other hand, the Nile flood period came when the summer crops were standing in the fields and if the water were to be left to override the banks of the river and flood the basins the whole crop would be ruined.

Figure 3.24 and the following table show the growth of population and cultivated and cropped land from 1821 to 1986. The population estimates in the table are actual census figures for the years 1897 to 1966 only. After the census of 1966 the estimates are projected figures based on the 1960 - 1966 growth rates rather than on vital statistics register. Agricultural land areas are from the Egyptian Central Agency for Statistics for the years 1897 - 1986. The figures are approximate as they may not have taken into account the agricultural land lost due to the fast rates of urban expansion since the 1970's.

The cultivated area increased from ca. 2 million feddans in 1821 to ca. 5 million feddans by the end of the nineteenth century and to 6 million feddans in the 1980's. Estimates of the arable

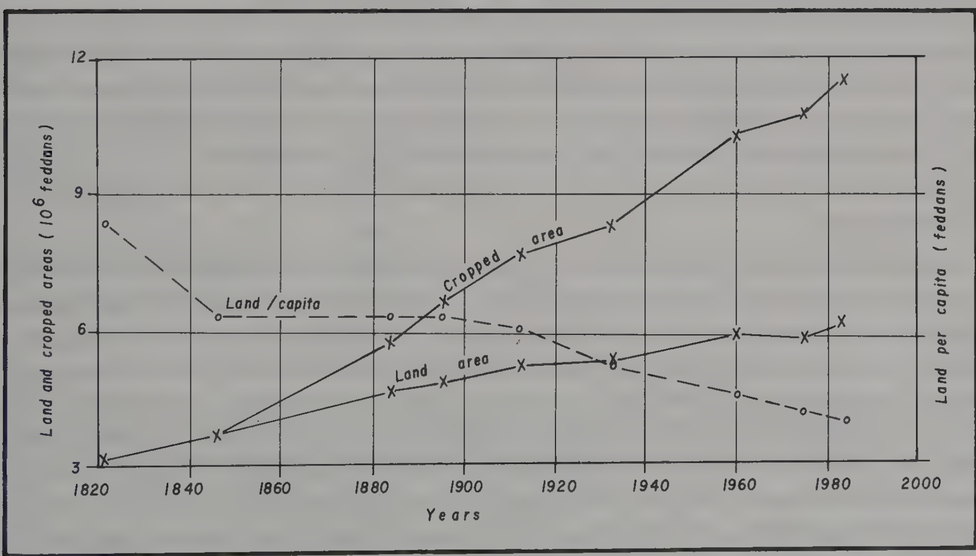

Fig. 3.24. Curve showing cultivated land, cropped areas and land per capita in Egypt 1820–1990.

Year	Population (million)	Cultivated Area (10^3 feddans)	Cropped Area (10^3 feddans)	Cropping Intensity (%)	Per Capita Cropped Area
1821	2.50	1956	1956	100	1.22
1846	4.48	3856	3856	100	0.72
1882	6.83	4621	5654	121	0.72
1897	9.73	4986	6725	136	0.71
1917	12.72	5633	7729	146	0.67
1937	15.92	5612	8302	156	0.53
1960	26.08	5900	10,200	173	0.39
1975	37.00	5700	10,700	188	0.29
1986	49.70	6100	11,400	190	0.23

land of Egypt vary a great deal depending on the government department issuing the figures. Below are some of the estimates given (in millions of feddans):

The Institute of Agricultural Economics: 6.625 (1982).

The Remote Sensing Center, Academy of Science and Technology: 6.090 (1979), based on the reading of satellite imagery.

Ministry of Reconstruction: 6.563 (1978), based also on the reading of satellite imagery.

Irrigation Department, Ministry of Public Works: 6.020 (1986), based on amount of water distributed to the fields.

Survey Department, Ministry of Public Works: 7.193 (1988), based on the reading of aerial photographs taken in 1985.

We shall assume that the arable lands of Egypt which are fully productive (the so-called old lands) are in the range of 6.1 million feddans and that the newly reclaimed lands that have not yet reached their full productivity are in the range of 750,000 feddans.

The growth in the cropped area was more spectacular as the land gave two or three crops per year. By the turn of the twentieth century the cropped area was nearly 7 million feddans and by 1986 it was 11.4 million feddans; the cropping intensity increased to 190 percent. Most of the increase was in the summer and flood crops. In 1988 the cropped area was used as follows (in feddans): 5,133,000 for winter crops, 4,930,000 for summer crops, 734,000 for flood crops and 600,000 for fruit groves.

In the meantime, the population of Egypt increased from 2.5 million in 1821 to almost 10 million by the end of the nineteenth century and to 50 million in 1986. During the last 50 years the cultivated area increased from 5 million to 6 million feddans while the population increased three and a half times. The cropped area, in the meantime, increased 140 percent. The increase in population resulted in a decrease in the per capita share of cropped area from 0.53 feddan in 1937 to 0.23 feddan in 1986. But the productivity of the land increased four times during the past 50 years (at the annual rate of 2.7 percent). If productivity figures are taken into consideration, it becomes obvious that the per capita value of agricultural production in Egypt has not decreased during the past two centuries as the land per capita figures may lead us to believe. This makes the smaller per capita area of 1986 a source of greater wealth than the larger per capita area of 1937. During the last 10 years (1979–1989) the average produce of one acre

of land increased from 1.4 to 2.1 tons in the case of wheat, from 1.6 to 2.1 tons in the case of maize, from 2.3 to 2.6 tons in the case of rice, from one to 1.3 tons in the case of beans, from 0.44 to 0.82 tons in the case of lentils, from 20.6 to 31.5 tons in the case of onions and from 33.5 to 40.2 tons in the case of sugarcane. For an excellent discussion of Egypt's agricultural potential see the study of Mitchell (1991).

4.2. Irrigated Agriculture comes to the Sudan

Save for several small and isolated flood plain strips in Nubia and northern Sudan which were cultivated under the system of basin irrigation, dry farming had been the pattern of agriculture in the Sudan. Basin lands amounted to about 70,000 feddans. It was only at the beginning of the twentieth century that the Sudan started irrigated agriculture on a large scale. At the behest of and with the financial backing of English weaving companies the Sudan started to grow cotton. In 1910 a small pilot area in the Gezira province (triangle between the Blue and the White Niles) was cultivated using pumps (Fig. 3.25). This soon grew to 6000 feddans in 1914 and to 40,000 feddans in 1921. A major break-through in the history of irrigated agriculture in the Sudan occurred with the erection of the Sennar Dam on the Blue Nile in 1925 with a storage capacity of 0.6 billion cubic meters of water. It expanded the cotton plantations in the Gezira area to 300,000 feddans in 1926 and to one million feddans in 1955. Soon after the building of the Aswan High Dam, which gave the Sudan a large share of the waters stored behind the dam, and the erection of the Roseiris Dam (with a storage capacity of 2.7 billion cubic meters of water) on the Blue Nile in 1966 the Government of the Sudan embarked in the sixties on major extensions of the Gezira project, increasing it through the Managil scheme to 2.1 million feddans. A project on the Rahad tributary of the Blue Nile added about 300,000 feddans. The Managil and the Rahad projects were made possible by the available water stored behind the Roseiris Dam. Other major schemes included the New Halfa lands (449,000 feddans) irrigated by the water made available by the Khashm el-Girba Dam on the Atbara River which was completed in 1966 with a storage capacity of 1.3 billion cubic meters of water. Pump stations on the Blue and White Niles added another million feddans. Cropping intensity in the Sudan was about 67 percent in 1986 (Chesworth 1990). Below is a breakdown of the major land reclamation schemes in the Sudan (in thousands of feddans):

Gezira and Managil	2100
Rahad	300
Khashm el-Girba	449
Pump stations on Blue Nile	604
Pump stations on White Nile	570
Pump stations on Main Nile	350
Total	4373

Figure 3.26 shows the growth of population and irrigated areas of the Sudan from 1900 to 1986. Like many other economic indicators of the Sudan which declined in the 1980's, the area of irrigated land also decreased.

The amount of water used by the Sudan increased steadily from about 7 billion cubic meters in 1970 to an average of about 13 billion cubic meters per year in the 1980's. This is still less than the amount allotted to the Sudan according to the 1959 Nile Water Agreement.

Fig. 3.25. Irrigated areas in the Sudan.

4.3. Century (Over-year) Storage Schemes

The system of seasonal storage was a step forward in meeting the needs of summer agriculture. It stored part of the excess water of the flood season which was then channeled for use during the following low season. The system, however, was not capable of storing all the water that came during flood time; close to 58 percent of that water was wasted into the Mediterranean during the height of the flood season. The system also failed to meet the consequences of the long-range fluctuations of the river; for although it succeeded in supplying Egyptian agriculture with its needed timely water during years of average flood, it failed to do so in years of exceptionally low floods. During these years the amount of water stored was smaller than the amount needed, leaving many lands uncultivated. During years of high flood, on the other hand, the land was overrun by the excess waters. With the river confined to its

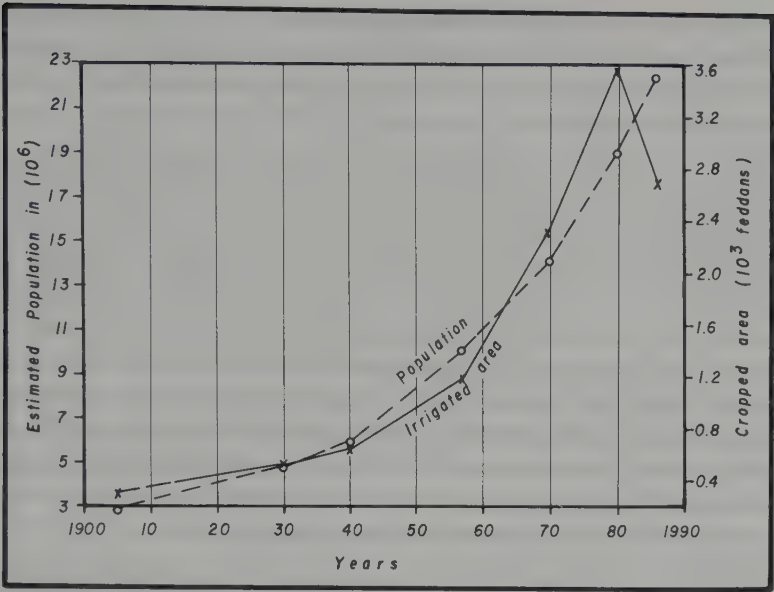

Fig. 3.26. Growth of irrigated areas and the population in the Sudan, 1900–1986 (after Chesworth 1990).

channel under the system of perennial irrigation, years of exceptionally high floods became exceptionally devastating. Egypt was still captive to the vagaries and moods of the river.

To counter these failures and to ensure a constant supply of timely waters over the years, the idea was advanced to make use of the excess waters of the flood, especially in years with above average supply, in years with below average supply. The devising of an over-year storage scheme (the so-called century storage) became the primary occupation of the Egyptian Ministry of Irrigation during almost all the years of the twentieth century.

Schemes of over-year storage passed through two stages. The first, which lasted to the middle of the twentieth century, involved schemes which treated the Nile Basin as one unit. They included projects aimed at controlling the sources of the Nile and regulating its flow to Egypt and the Sudan, the primary benefactors of these schemes. The second came with the Egyptian revolution of 1952 and the realization that there were difficulties in implementing the projects of the first stage of the century storage scheme. Hence the second stage concentrated on projects within the borders of Egypt and the Sudan.

4.3.1. Upper Nile Century storage scheme

Over-year storage schemes were first conceived in Cairo at the beginning of the twentieth century. Egypt was then the only basin state which made use of the waters of the Nile. Its expanding economy and growing population mandated an ample and a constant water supply which Egypt thought it could secure from the headwaters of the Nile. Egypt's concern about safeguarding the sources of the Nile has had a long tradition and was the drive behind the military and exploration expeditions carried out in the areas of the headwaters of the Nile in the early years of the nineteenth century. It began drawing plans for their control and regulation from a

view point that the Nile Basin constituted a single hydrological unit. At that time the whole of the Nile Basin constituted one political unit under British rule. It was this concept of the unity of the Nile Basin which dominated all the Nile control projects until the mid twentieth century long after British rule had ended.

There was some logic in this view. To the Egyptians there seemed to be more water in the upper reaches of the Nile system than anyone could conceivably use. There was also little reason to fear the upstream riparians. None had the forces which could pose a credible military or economic threat and none had the technology or the motivation to tamper with the waters of the river. It is true that the entry of the Sudan as a consumer of the waters of the Nile in the 1920's had caused anxiety in Egypt, but that was countered by the belief that both Egypt and the Sudan complimented each other and that it was beneficial for both to be united. National sentiment in both the Sudan and Egypt, and until the advent of the Egyptian revolution of 1952, advocated the unity of both countries under one king and one flag. One of the slogans which left an impact on a whole generation of politicians was the statement made by the Egyptian leader Mustafa el-Nahas in 1930 during negotiations with Britain over Egyptian independence "I would rather have my hand severed than see the Sudan severed from Egypt".

The first overall plan for the control of the waters of the Nile was made shortly after the turn of this century. It was envisaged by Sir William Garstin who in 1904 published a plan involving the entire Nile Basin. The plan consisted of an integrated series of projects of seasonal and over-year storage (Garstin 1904). The essential element of the plan was the building of a discharge regulator at the outlet of Lake Albert in order to use it for over-year storage and allow the water thus stored to pass through the Sudd swamps. To minimize loss from evaporation in the Sudd, Garstin suggested dredging and improving the channel of Bahr el-Zaraf in order to cut the losses down. The water thus procured was to go in its entirety to Egypt, the main user of the waters of the Nile. He also suggested increasing the storage capacity at the Aswan Dam (the first stage of which had barely been finished) and utilizing the Wadi Rayan depression (a hollowed depression which lies below sea level to the southwest of the Fayum depression) to store excess flood waters downstream from Aswan. For the Sudan he proposed allowing it to use the waters of the Blue Nile when in flood.

It is interesting to note here that Garstin's integrated plan directed the largest part of the waters of the entire Nile Basin to Egypt. At the turn of the century this "Egyptocentric" attitude, to use John Waterbury's expression (Waterbury 1979), was uncontested in the absence of any claim by other riparians. The Nile waters played no significant role in their life; most of their agriculture depended on rain. Furthermore, Egypt was the only country which was totally dependent on the Nile for its existence.

In addition to the pioneering water storage plan proposed by Garstin, Sir M. McDonald developed in 1920 another plan which included seasonal storage reservoirs at Sennar (on the Blue Nile) and Gebel Aulia (on the White Nile near Khartoum), a flood control barrage at Naga Hammadi (310 kilometers north of Aswan), a channel through the Sudd region, and over-year storage reservoirs at Lakes Albert and Tana (McDonald 1920). It is worth noting that all the seasonal storage reservoirs proposed in this plan have since been built. MacDonald's plan and in particular his proposal to build the Sennar dam on the Blue Nile was not without controversy. McDonald's plan and in particular his proposal to build the Sennar dam on the Blue Nile in the Sudan did not get the approval of William Willcocks, the notable Nile hydrologist, who designed

the Aswan Dam and continued to live in Cairo after his retirement from the Egyptian Irrigation service. Arguing from an Egyptian point of view, he severely criticized the building of the Sennar dam which McDonald claimed would not jeopardize Egypt's interests. To this, William Willcocks objected, accusing McDonald of forging the hydrological records in order to come to the conclusion that it was not harmful to Egypt. In 1920 McDonald published a report in which he documented his plan with figures of discharges that were to substantiate his proposals. The report was examined by a Nile Waters Commission which found the figures accurate and concluded that there was no basis for Willcocks' charges. This did not stop Willcocks from attacking McDonald, who finally filed libel charges against Willcocks. Willcocks was found guilty in 1925.

The final plan for the full utilization of the waters of the Nile came in 1946 and was published under the title "*The future conservation of the waters of the Nile*" by The Egyptian Ministry of Public Works (Hurst, Black & Simaika 1946). It crowned the efforts of the Nile Control Department of the Egyptian irrigation authorities. It was based on extensive data gathered as a result of laborious research conducted by the department on the river along its entire length. The plan included a series of complicated engineering projects in eight African states: The Sudan, Ethiopia, Uganda, Tanzania, Kenya, Zaire, Rwanda and Burundi. It was adopted by the Egyptian Cabinet on December 28, 1949 as part of national policy. It is interesting to note here that Egypt up to that time, long after it had lost control over the headwaters of the Nile, was still of the belief that it could convince the riparian states to execute in their lands, projects that had been drawn in its own government departments. The scheme was believed to be beneficial to all basin states. For Egypt and the Sudan it would have given them the water they needed for their expansion schemes in agriculture; for the other basin states it would have harnessed the river and opened great expanses of their land for exploitation. Irrigated agriculture had not yet been introduced in any of these states and water was abundant and left without use in many of them.

The Century storage plan involved several projects (Fig. 3.27). Phase I of the plan comprised the building of reservoirs on the lakes of equatorial Africa and Ethiopia as well as a canal to deliver the water that was to be stored in the equatorial lakes across the Sudd region. Phase II of the plan comprised projects aimed at reducing water losses in the Sobat and Bahr el-Ghazal basins.

4.3.1.1. Phase I of the Century storage scheme

(a) The equatorial lakes reservoirs

The linchpin of the plan was the use of the equatorial lakes as reservoirs. These lakes would make perfect reservoirs because losses by evaporation from their surfaces would be minimal being roughly balanced by rainfall. Unlike the reservoirs on the Blue Nile or the Main Nile, they would have the further advantage of not facing the threat of siltation. Among all the equatorial lakes, Lake Albert was singled out as most fit for storing water. As it lies in the Rift Valley its shores are steep and its surface-to-capacity relationship favors low evaporation losses per unit volume. The Century storage scheme envisaged the construction of an over-year storage reservoir at Lake Albert combined with a regulator at Lake Victoria. The reservoir at Lake Albert would end at Nimule on the Sudan–Uganda border where a dam was to be built. A dam with the height of the Aswan Dam would have a storage capacity of close to 140 billion cubic meters or more than twenty-five times the capacity of the old Aswan dam.

The effective use of the proposed reservoir at Lake Albert would be greatly enhanced by regulating the discharge from Lake Victoria. A steady discharge from this lake would reduce the variations in the inflows to Lake Albert and would increase its effective storage capacity. It is significant to note here that the Lake Victoria reservoir was the only part of the century storage scheme which was implemented. It formed consequent to the building of the Owen Falls Dam

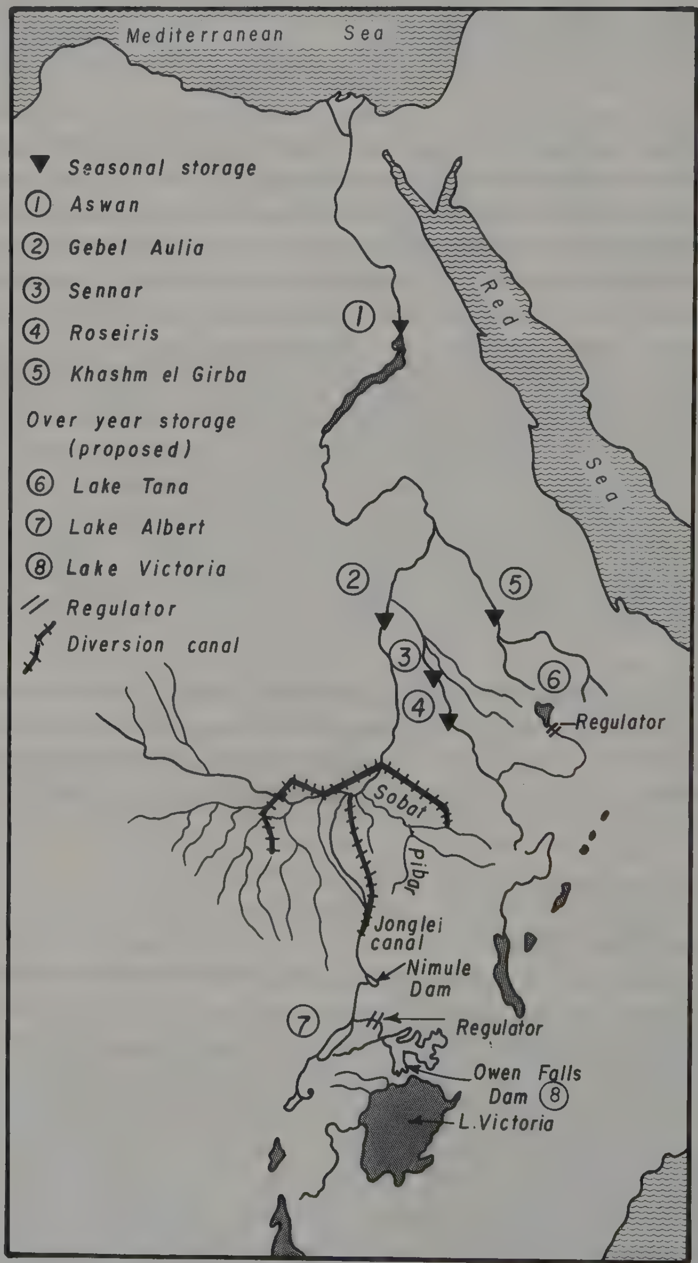

Fig. 3.27. Seasonal storage facilities and proposed over-year storage sites.

(1948–1954) about 3 kilometers north of the exit of the lake. The dam was initially proposed by Uganda for hydroelectric generation for its benefit and was agreed upon by Egypt which saw that it fitted its plans for the development of the headwaters of the Nile. The concrete gravity dam is 726 meters long and 30 meters high. It has a storage capacity of 120 billion cubic meters and an installed 150 megawatt power station. At the request of the Egyptian Government, Uganda increased the height of the dam by one meter to provide about 67 billion cubic meters of additional storage capacity that would be used for irrigation purposes during low years. Egypt contributed to the cost of the construction and compensated Uganda for damages incurred by lakeside residents as a result of the increased level of Lake Victoria. The actual regulation of Lake Victoria was primarily focused on hydropower generation. Egypt's involvement was principally part of a long range strategy aimed at executing the century storage plan; however, storage in Lake Victoria could not be effectively utilized unless the Lake Albert reservoir and the Jonglei Canal projects were to be completed.

(b) The Jonglei Canal

The water stored in the equatorial lakes would be of no value if it were not to be channeled through the massive Sudd region, and for this the plan involved the cutting of a diversion canal to carry water past the Sudd swamps. For a long time it was thought that it would be possible to improve the flow of the Sudd swamps by enforcing the embankments of Bahr el-Gebel to avoid spillage and to confine the water to its channel. In 1938 this idea was abandoned in preference for a bypass canal. The canal was to take off at Jonglei and to skirt the swamp to the east for some 280 kilometers, delivering its discharge to the Nile at Malakal (Fig. 3.28). This part of the century storage scheme was the subject of an agreement between Egypt and the Sudan in June 1974. The digging of the canal began in June 1978 and was greatly hastened by the use of a gigantic piece of earth-moving equipment, the "bucketwheel", which was capable of excavating between 2500 to 3500 cubic meters an hour or 300,000 to 500,000 cubic meters a week, extending the canal at a rate of about two kilometers every 6 days. The work, however, came to a halt in 1983 as a result of the civil war raging in the Sudan.

From its inception the social and environmental impacts of the Jonglei Canal have been the subject of controversy (Howell, Lock & Cobb 1988). Its critics maintain that the seasonal pattern of its discharge would invert the Sudd's natural regime and adversely affect the populations of the area. The people living along the canal consist mainly of pastoral tribes subsisting on rainy season agriculture and year-round cattle raising. They belong to the Mandari, Dinka, Nuer and Shilluk tribes. They numbered about 260,000, tending some 450,000 heads of cattle, according to a survey which was undertaken in 1969. Some of the environmentalists argue that the canal would disturb the life style of these nilotic people. Most establish their permanent settlements on high ground, generally to the east of the swamp, where they cultivate millet and sorghum during the rainy season from May to October. During the dry season when the upland pasture dries out, the herdsmen move westward and down toward the flood plain areas from which the swamp has receded. The islands of pasturage that thus emerge constitute the "toich" lands and are sufficient to provide adequate grazing throughout the dry season. In that capacity the toiches are essential for the survival of the pastoral tribes. The digging of the canal would not only threaten substantial areas of the toich lands with desiccation but would also stand in the way of the herdsmen's journey with their cattle to and from these lands.

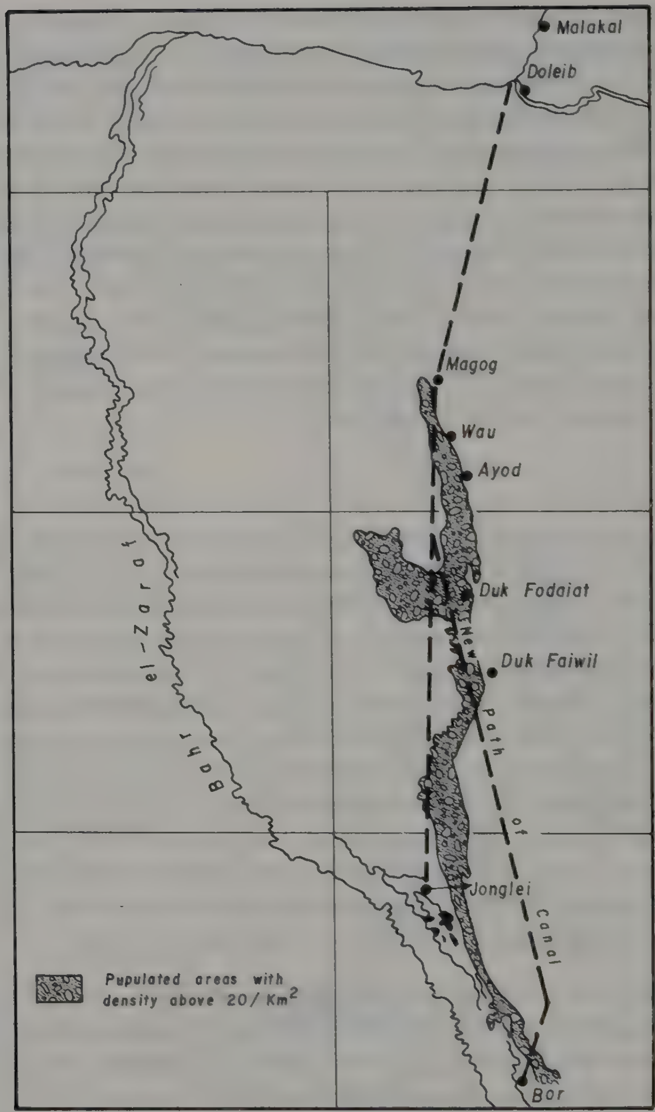

Fig. 3.28. Jonglei Canal showing population density and new path of the canal (modified after Waterbury 1982).

The original plan of the canal was made in 1947–1954 was revised in 1969 and 1975. Among the revisions recommended by the environmentalists was the shifting of the alignment of the canal eastward in its southern half so that the majority of the inhabitants of the region would not have to cross the canal with their cattle. Inspite of the fact that this shift would have increased the length of the canal from 280 to 360 kilometers, the President of the Sudan approved the shift under intense lobbying (Waterbury 1982).

On the other hand, there are many who believe that the advantages of the canal far outweigh the disadvantages. Admittedly, it will change certain aspects of the life style of the people living

in the area, but there will be improvements in transportation, water supply and other infrastructure that will ultimately bring a wide range of new economic alternatives to a people primarily dependent on herding, cultivation and fishing. Already the population of the southern Sudan has gradually come round to seeing the benfits of the canal. It would reduce flooding in inhabited areas around Zaraf Island and facilitate the movement of goods and people in the region by virtue of the canal and the road along its embankment. Moreover, it would provide a year-round supply of water for animals and agriculture.

The water saved by the digging of the canal would be shared equally by Egypt and the Sudan who would also shoulder the expenses equally. The canal is designed to have a capacity of 25 million cubic meters per day in its first phase, to be increased to 55 million cubic meters in the second phase. After finishing the first phase of the canal, 9.1 billion cubic meters of water (out of a total of 33 billion cubic meters that enter the Sudd at Mongalla) would be directed to the canal leaving 23.9 billion cubic meters to pass through the Sudd. Assuming that the conveyance loss in the canal is about one billion cubic meters and the evapotranspiration loss in the Sudd about 10.7 billion cubic meters, the amount which would exit from the Sudd would be 21.2 billion cubic meters. Without the canal the amount of water that would exit from the Sudd would be about 16.5 billion cubic meters. This means that there would be a gain of about 4.7 billion cubic meters after the completion of the first phase of the canal. Subtracting 19 percent from this amount as conveyance losses until the water reaches its destination in Egypt and the Sudan the net gain would be 3.8 billion cubic meters or 1.9 billion cubic meters for each of the two countries. The execution of phase II of the Jonglei canal would almost double the share of each so as to provide both Egypt and the Sudan with 7 billion cubic meters of timely waters from December to July. However, this phase cannot be executed before the building of the Lake Albert reservoir to secure enough water to be channeled through the canal.

(c) The Lake Tana Reservoir

An important element of the century storage scheme was the proposal to use Lake Tana for over-year storage. Lake Tana (elevation 1760 meters above sea level) has an area of 3100 square kilometers. The scheme involved the building of a dam on the Blue Nile at the outlet of the lake to raise its level by one meter in the first phase and by another meter in the second phase of the project. The first phase would provide a water reserve of 3.3 billion cubic meters and would assure Egypt of summer supplies at Aswan of 2.1 billion cubic meters in a normal year (after taking into consideration all evaporation and conveyance losses). The second phase of the reservoir would provide the Sudan with 2.4 billion cubic meters. The damming of the lake could be a source of hydroelectric power for Ethiopia and would also regulate the flow of the water of the Nile and protect Egypt and the Sudan from the damages of high floods (Whittington & Guariso 1983).

Although the total storage capacity is small compared to that of Lake Albert, Lake Tana is very useful as part of the scheme. Its stored water could be channeled to the Sudan at a considerably lower cost; there would be no need to go through expensive projects of digging diversionary canals as in the case of the proposed equatorial lake reservoirs. Furthermore, since the rainfall on the Equatorial Plateau is independent from that on the Ethiopian Highlands, over-year storage in both source areas of the Nile would provide more security against a series of low years than if the same storage capacity were to be located solely in one area.

(d) The Fourth Cataract Dam

The last control structure of the century storage scheme was an additional seasonal storage reservoir on the Main Nile at Merowe (the Fourth Cataract) between Atbara and Wadi Halfa. It was suggested for flood control, the securing of summer water and the improved coordination of upstream storage facilities. In its original plan the proposed capacity of this seasonal storage facility was about 3 billion cubic meters. However, the construction of the High Dam has eliminated the basis for these objectives, and the scheme is sometimes mentioned in Sudan's plans as a possible site for the generation of hydroelectric power and lately as a reservoir of water in excess of 7 billion cubic meters.

(e) Amount of water stored

This first phase of the century storage scheme would in effect double the water available to Egypt and the Sudan. When the scheme was proposed the water storage facilites that existed in these two countries dammed some 13 billion cubic meters: the old Aswan (5.2 billion), the Gebel Aulia (3.5 billion), the Sennar (0.6 billion), the Roseiris (2.7 billion) and the Khashm el-Girba (1.3 billion). The first phase of the proposed century storage schemes would add 9.3 billion cubic meters of water which would come from the equatorial lake reservoirs via Jonglei Canal (4 billion), Lake Tana (2.3 billion) and the Fourth Cataract (3 billion). The quantity of water delivered after this phase would be increased by another 3 billion cubic meters after the completion of phase II of the Jonglei project.

4.3.1.2. Phase II of the Century storage scheme

Phase II of the century storage scheme included several projects aimed at limiting the water losses in the Sobat and Bahr el-Ghazal basins (Fig. 3.29). These projects were not fully studied or examined in detail with regard to their engineering aspects, social and environmental impact or cost. There were two alternative proposals for the Sobat basin. One proposal would construct a seasonal storage facility on the Baro at Gambeila. This would reduce spillage on the Baro by 3.8 billion cubic meters per year. The second proposal would involve embanking the Baro at the point of maximum spill and excavating a diversion canal of 400 kilometers from Khor Machar northwest to the White Nile at Melut. This would increase the White Nile discharge by 4.4 billion cubic meters per year. Two diversion canals, Bahr el-Ghazal south and Bahr el-Ghazal north, were proposed to avoid the vast swamps of this basin. The first would be a canal, 425 kilometers in length, beginning on the River Jur, going northwest to the Lol and then cutting across to the north of Bahr el-Ghazal to run east to the junction of Bahr el-Ghazal and Bahr el-Gebel at Lake No. This canal would save about 7 billion cubic meters. To counter the blocking effect of the Sobat, the flow of this diversion canal would be directed north of the Sobat mouth by excavating a second canal, the Bahr el-Ghazal north, 225 kilometers in length, from Lake No to the White Nile at Melut.

4.3.2. The Aswan High Dam

4.3.2.1. Historical

It has already been stated that Egypt, until the advent of the revolution of 1952, had adopted an over-year storage scheme which involved the entire Nile Basin and called for the erection of structures along the river in four states (Uganda, Zaire, Ethiopia and the Sudan). These structures would have affected the regimen of the river in four other

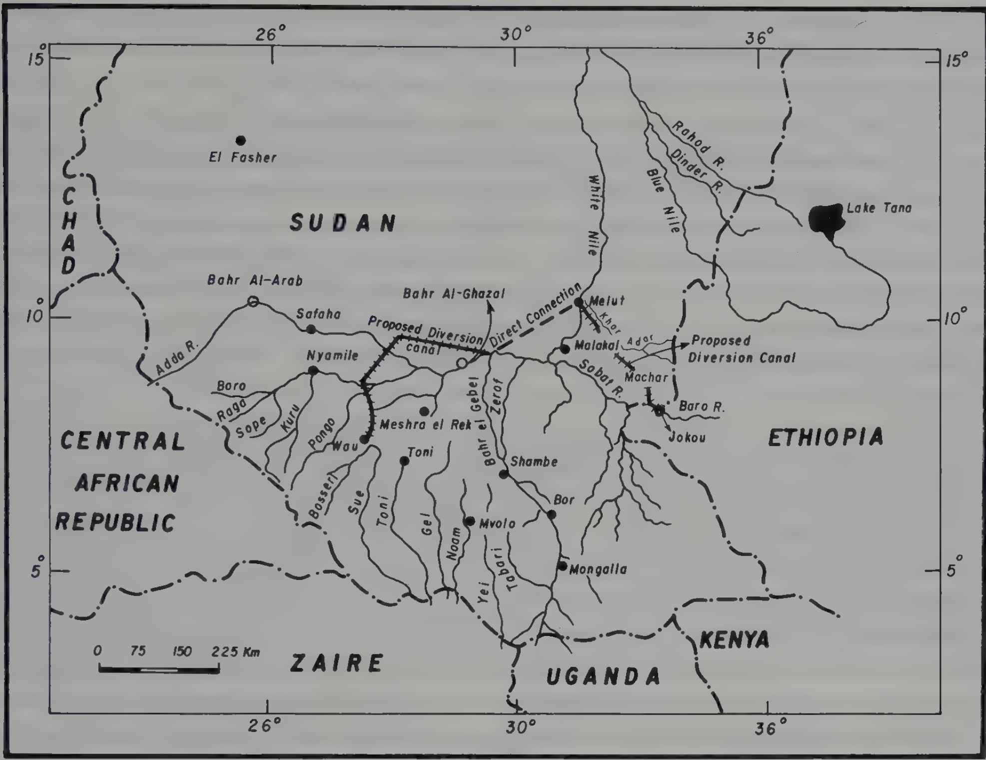

Fig. 3.29. Phase II of the Century Storage Scheme, proposed diversion canals.

basin states (Kenya, Tanzania, Rwanda and Burundi). A few years after the scheme was adopted, the political climate that had induced the formulation and adoption of the scheme changed radically when most of the basin states won their independence. The new states were not willing to accept a plan for the development of their natural resources which had not been drawn in their capitals. They wanted to affirm their national sovereignty by asserting their jurisdiction over their natural resources and their right to draw their national plans of development. It became obvious by the mid years of the twentieth century that the Nile development scheme, as it was conceived by the Nile Control Department in Cairo, was difficult to implement. The projects of the century storage scheme had to be postponed until these states had drawn their plans and were ready to build a vehicle for the integrated development of the river.

The officers of the 1952 revolution in Egypt realized this new geopolitical situation and looked for an alternative to secure, for Egypt, the water it would need if it were to develop its agricultural potential and meet the aspirations of its growing population. It was, therefore, with great interest that they viewed the project of Adrien Daninos, a Greek–Egyptian engineer, in which he proposed to build one single dam upstream of Aswan to effectively impound the entire flood of the Nile, affect over-year storage and generate an enormous amount of electricity. Adrien Daninos was a visionary who had crusaded for a long time for the utilization of the Nile waters in full and for the electrification of the old Aswan Dam after its second heightening in 1912. In 1948 he read a paper at the Institut d'Egypte (Daninos 1948) outlining these ideas; he

appropriately began his communication by a quotation from the Sainte Helene memoirs of Napoleon, the founder of the Institute in which he was reading the paper, "If I were to govern this country (Egypt) not one drop of water would be lost to the sea".

The idea was tempting to the officers of the Revolutionary Council. Here was a project that lay within the borders of Egypt; it could meet its rising water demands and free it from being hostage to upstream riparians for its economic survival. Looking at it from this perspective some 40 years later one can see that there was indeed some wisdom in favoring a site for the dam within the borders of Egypt. At the writing of this book there is hardly an upstream basin state which is not beset by discord, tribal wars, separatist movements or civil strife. Given these developments it would have been an extremely difficult if not an impossible undertaking to negotiate the building of a dam outside the borders of Egypt let alone to run it efficiently.

Inspite of the criticisms and perils that such an enormous structure could have brought about, including some that Daninos himself had pointed out, the Revolutionary Council forwarded the project for study to a select group of confidants made up of some members of the army corps of engineers and university professors. It was shown to be feasible. The project was then forwarded to the Ministry of Irrigation for study. The ministry found the project technically sound and capable of meeting Egypt's immediate needs. However, it did not consider the project a substitute for the century storage scheme but rather a complement to it; the full utilization of the waters of the Nile still remained in the realization of the projects proposed for its headwaters. Great losses by evaporation and seepage, which were previously held by the Ministry to be the main drawbacks of the Aswan High Dam project, were to be minimized by careful design. The studies of the Ministry were later published in full (Hurst, Black & Simaika 1966).

The project was then subjected to intensive engineering feasibility studies. In November 1952 it was forwarded for study to two German engineering firms, Hochtief and Dortmund. In early 1954 the firms presented the results of their study which called for a clay-core, rock-fill dam 6.5 kilometers upstream from the Old Aswan Dam. Their study and recommendations were then reviewed by an international advisory panel drawn from Germany, France and the United States. In December 1954 the panel endorsed the plan which was then forwarded to the British engineering firm of Alexander Gibb to draw up the design and specifications of the proposed dam.

The funding of the project was first sought from the International Bank for Reconstruction and Development (IBRD) which, it was hoped, would raise an aid package from Western countries to help finance the dam. After conducting its own study, the bank found the dam "technically sound and economically beneficial" and offered to the Egyptian Government in December 1955 a funding package of which one quarter was in the form of grants from the United States and the United Kingdom Governments. In July 1956 the offer was withdrawn by the United States on the pretext that the Egyptian economy "could not bear the strain of building the dam". The withdrawal was obviously politically motivated, for Eugene Black, the president of the bank, had written to the Egyptian Finance Minister, only a few days before, expressing the bank's confidence in the soundness of Egypt's economy. From the start the project was embroiled in the context of the cold war and superpower rivalries which were at their peak at that time. The United States, the major depositor in the bank, had the intention of using the funding of the project to lure Egypt into joining the regional defence pact for the Middle East which it had founded in Baghdad. When that did not materialize the funding was withdrawn.

The total cost of the Dam including the power station was estimated to be $1.3 billion, of which $400 million were to be in foreign exchange. The proposed financing of the project presented by the bank was to come in two successive stages. In the first stage the funding included a loan from the World Bank worth $200 million and grants from the United States and the United Kingdom worth $56 million and $14 million respectively. Stringent conditions were attached to the disbursement of the funds; Egypt's economy was to be subjected to the bank's periodic review, its power to incur foreign debts was to be restricted and its authority over the execution of the construction was to be limited. The second stage of funding was promised only after the termination of the first stage. These conditions and the two-stage funding aroused Egypt's suspicion that the bank's offer was being used to hold its economy captive and to force it to change its foreign policy. That suspicion became abundantly clear when the offer was withdrawn even after Egypt had accepted all its terms. Details of the Egyptian World Bank negotiations on the financing of the Aswan High Dam and the impact of the political events of the time are given in Heikal (1988) and in Waterbury (1979). Among the most significant events of this period was the unprovoked Israeli raid in February 1955 on the Gaza strip, which was then under Egyptian control, in which the Egyptian army suffered a humiliating defeat. The raid forced the Egyptians to look into the world market for armament deliveries and led ultimately to the Czechoslovak arms deal of some $200 million in advanced Soviet weaponry and aircraft. The withdrawal of the World Bank's loan was certainly tied to Egypt's defiance of the western embargo on arms to Arab nations in a state of war with Israel.

The two years that followed the withdrawal of the bank's offer were fateful years in the history of modern Egypt. They included, among other events, the nationalization of the Suez Canal Company in July 1956 in response to the withdrawal of the funding of the bank and the ensuing Suez war in which France, Britain and Israel openly sought to overthrow Egypt's government and recapture the canal. Although the conspiracy failed, nothing was done about the funding of the dam until December 1958 when a formal agreement was signed with the Soviet Union which offered a loan of 400 million rubles toward the first stage of the construction of the dam. Soviet experts reviewed the plans of the dam and in May 1959 presented their own which were basically those of Hochtief and Dortmund's with some modifications which included, among other things, changing the position of the power station, shortening the north–south length of the dam and proposing the use of a well-tested Soviet technique for sluicing and compacting sand in the dam's core. In July 1959 another agreement was signed with the Soviet Union in which an additional loan of 500 million rubles toward the completion of the second stage was promised. With the funding already at hand, there remained the important step of getting the approval of the Sudan, the other principal beneficiary of the waters of the Nile, for the building of the dam. That approval and the ways by which the dam was to be managed and its waters apportioned was the subject of an agreement signed in December 1959 (see also Part IV). Immediately thereafter work at the dam site began in January 1960, almost eight fateful years after the project had been endorsed by the Revolutionary Council.

The dam was completed and became fully operational in 1970. It was inaugurated in an official ceremony in January 1971 which was attended by Anwar el-Sadat, Egypt's new head of state, and President Nikolai Podgorny of the Soviet Union. Gamal Abdel Nasser, the president of Egypt during the fateful years of the building of the dam and the leader of the many battles that Egypt had to fight in order to complete its building, did not live to see that day. He had died in September 1970.

No single project has aroused more controversy than the High Dam. For most Egyptians it became a symbol of patriotism and determination, the mainstay of the economy and the hope for the future. Those who harbored dislike for President Nasser's politics, which had led to the erection of a successful Soviet monument in Egypt, vilified the dam as a catastrophe. It had brought nothing to Egypt but disaster. Sterling Claire (1972) assumed that the dam was a great folly and that it would never fill because of seepage and evaporation. Egyptian journalists wrote long articles in the mid 1970's which questioned the wisdom of the building of the dam and blamed it for most of Egypt's economic ills. Most of the articles were not scholarly, coming with the wave which challenged Nasser's legacy after the accession of Anwar el-Sadat to power. For the environmentalists it was a mammoth structure that disturbed the ecological balance and brought about changes and a legacy of unsurpassed cultural and physical destruction. It was taken as a model of the bad effects of large dams in a book published by the Sierra Club (Goldsmith & Hildyard 1984). From the start many of the consequences that an enormous structure such as the High Dam could bring were recognized by scientists and engineers who were in favor of the building of the dam. There were those who thought that the reservoir would rapidly silt up, while others were of the opinion that the damming of the water at Aswan would cause downstream scouring of the river bed and enhance coastal erosion as more energy would be released when the river no longer carried its load of suspended matter. Hurst and other Egyptian Ministry of Irrigation engineers were at first skeptical about the choice of Aswan as the place for storing water; expected excessive rates of evaporation would reduce the capacity of the reservoir and cancel its benefits.

After the decision was taken to go ahead with the building of the dam public criticism of the project was not encouraged, and when the funding negotiations began to stall all criticism was viewed with suspicion. Among the early critics of the project none has become better known than Engineer Abdel Aziz Ahmad who not only went public with his criticism but did it in a British forum during the height of the Suez crisis. Abdel Aziz Ahmad was disgraced after the publication of his report in the British forum. He became a controversial figure. For the anti-Nasserists he was a great hero who had the courage to challenge the regime and was awarded, in an act of significant defiance, the State Prize for Oustanding Achievement by the Science Council in 1964, but the award was reversed from high. The Prize was reinstated posthumously in 1976. His arguments were the basis of Claire Sterling's article that the dam would never fill. For the Nasserists his arguments were motivated by his hate of the new regime of Nasser, had no basis in fact and should not be taken seriously. They were rebutted by Abu el-Ata on the scientific level (1978) and by Philippe Gallab on the political level (1974). Ahmad read (and later published) his report in the British Institute of Civil Engineers (1960). It concentrated on the water losses that the building of the dam would bring about. He attempted to show that the evaporation and seepage rates of the newly created lake would be so high that they would annul the benefits that could acrue from the dam. He predicted a higher rate of evaporation than had been estimated in previous studies if the wind factor were to be taken into consideration. He also anticipated a very high seepage rate and a continuous lateral infusion of the waters of the dam to the surrounding underground reservoir, whose water table has a considerably lower level than that of the dam; the dam would never fill or would not fill before the turn of the century. Twenty years after the building of the dam none of the prognostications of Dr Ahmad have been confirmed. The dam filled to its safe storage levels in 1975. Evaporation and seepage, although high, have not surpassed those originally expected. Seepage and lateral infusion practically

stopped a decade after the construction of the dam according to a study by the Aswan High Dam Authority (Abu el-Wafa & Labib 1970) and by the members of the Water Master Plan Project (Carr & Khafagi 1981). The latter authors estimated the reduction of the seepage from the dam to the surrounding underground aquifer from about 5 million cubic meters a year prior to the building of the dam to about 1.6 million cubic meters after the impoundment of the water in the dam.

4.3.2.2. The High Dam

The construction of the dam took place in two steps. The first was the diversion of the river and the construction of coffer dams along its path to close off that part of its course where the main body of the dam was to be built . This step was finished in May 1964 with Presidents Nasser and Khrushchev witnessing the closure of the Nile. The second step was the building of the main body of the dam, an edifice some 980 meters wide at its base, made up of a clay core, capped by rock fill, buttressed by walls of impacted sand, and flanked by the up- and downstream coffer dams (Figs 3.30 & 3.31). The crest of the dam stands 111 meters above the river bed (which lies about 85 meters above sea level), and the whole structure is anchored upon the sediment on which it rests by a grout curtain thrust over 200 meters down to the granite substratum. The location of the High Dam was chosen with the expectation that the granite substratum would be reached at a small depth. This, however, was not the case. The site proved to be an ancient river bed which had been scoured to great depths in times past (see Part I, p. 39) and then filled with silt. The grout curtain which had to pass through the entire column of silt to the granite substratum is one of the longest in the world.

The dam is one of the great engineering works in the world. It is the second largest in the world; the hydropower station is the eighth largest. The volume of construction materials that went into it amounted to more than 42 million cubic meters. Its crest extends for 3600 meters, of which 520 meters are over the river bed, 2325 meters on the east bank and 755 meters on the west bank. The width of its crest is 40 meters. On the east side of the dam is the powerhouse transecting the diversion channel. Six tunnels feed water through twelve turbines (each with a capacity of 175,000 kilowatt hours) which have the capacity to generate 10 billion kilowatt hours per year. The final cost

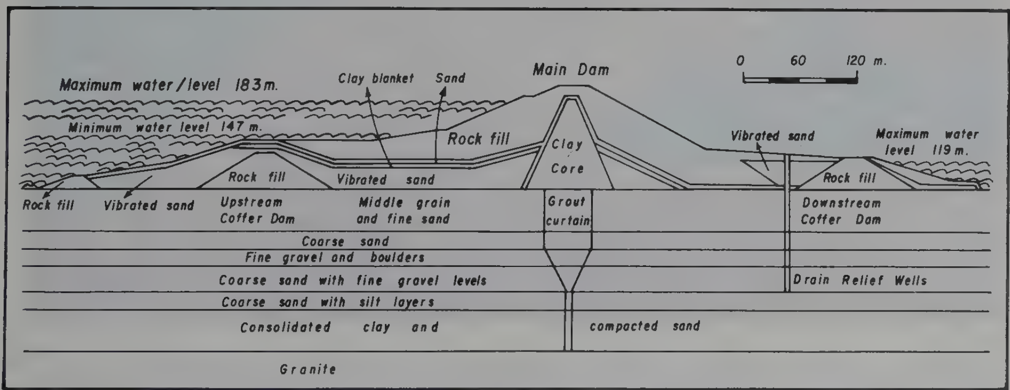

Fig. 3.30. Cross section of the High Dam.

of the building of the main body of the High Dam and the power station was \$820 million which were all paid off by 1978 . These estimates do not include the cost of land reclaimed as a result of the additional water provided by the dam nor any of the projects undertaken to counter the side-effects of the dam. A study of the cost-benefit analysis of the dam is given in El-Feel (1974).

4.3.2.3. The reservoir

After the incorporation of the upstream coffer dam in 1964 the reservoir slowly began to fill. The reservoir was originally designed to have a maximum water level of 98 meters above bed level in Aswan, or 183 meters above sea level, and a total capacity of 162 billion cubic meters. At this level the reservoir has a length of close to 500 kilometers and an average width of 12 kilometers, with numerous side arms or bays (*Khours*) extending in both the Egyptian and Sudanese stretches of the Nubian Nile (Fig. 3.32). The surface area of the reservoir at this maximum water level is 6540 square kilometers. The reservoir is called Lake Nasser in its Egyptian portion and Lake Nubia in its Sudanese portion. Because the reservoir forms one body of water many authors refer to the entire reservoir simply as Lake Nasser. The dead storage capacity of the reservoir is that portion which is reserved for silt accumulation. It is estimated to be slightly less than 20 percent of the total capacity.

In practice, the reservoir has never reached its maximum level. After rising gradually from 1964 to 1973, it rose significantly as a result of the successive high floods of 1973

Fig. 3.31. Overview of the High Dam (card accompanying invitation to the opening ceremony of the dam 1971).

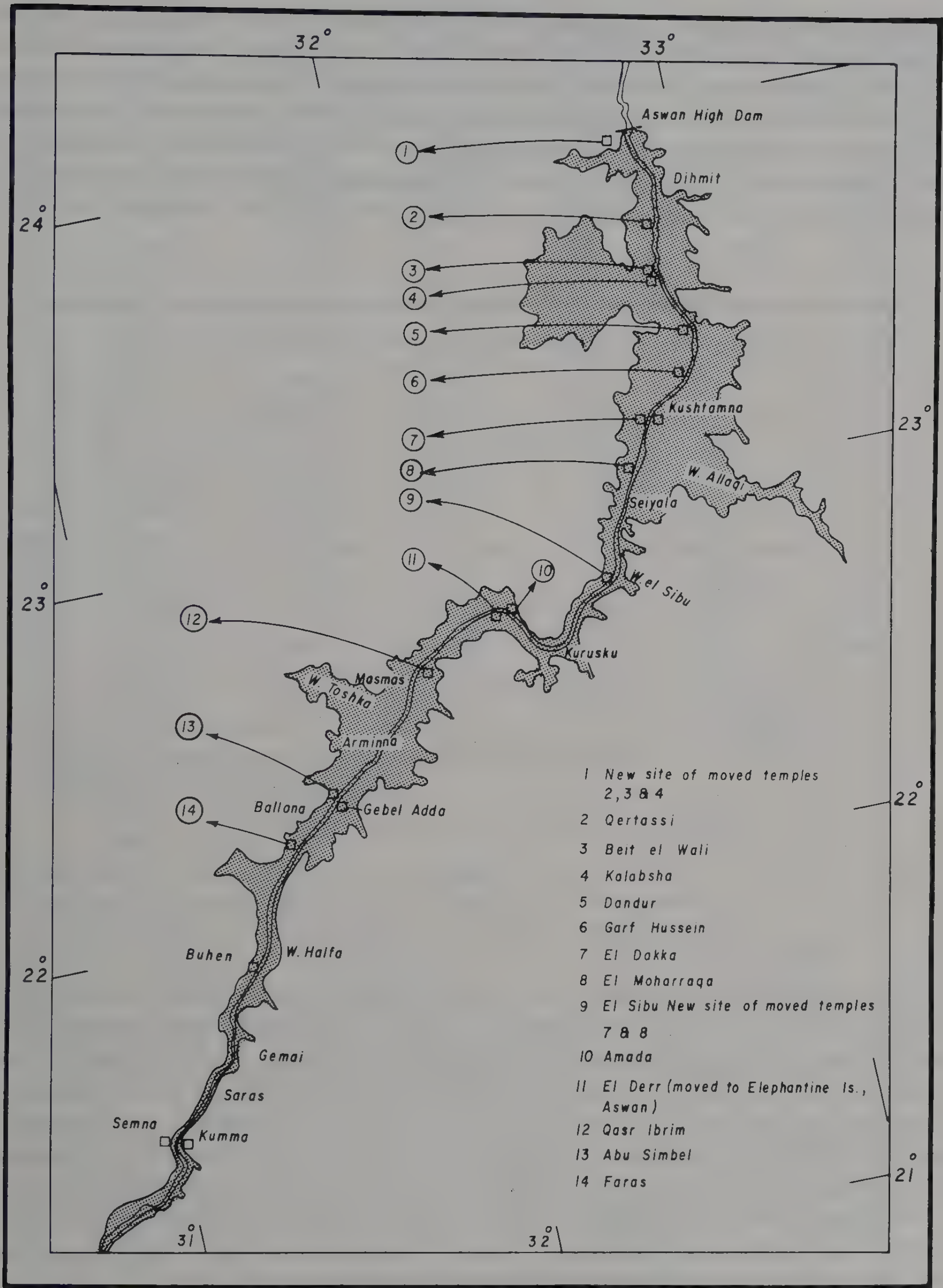

Fig. 3.32. Map of Lake Nasser.

and 1974. During these two years alone the level rose close to 10 meters to the level of 176 meters and the capacity increased about 150 percent. At that level the reservoir capacity is 126.5 billion cubic meters and its area 5358 square kilometers. In 1978 the reservoir reached

the highest level (178 meters) and greatest area (5738 square kilometers) it has ever reached. Its capacity rose to 137.5 billion cubic meters and its live storage reached its maximum (100 billion cubic meters). After 1978 the water level started to decrease as a result of the low Nile flows of the early 1980's until it reached its lowest level of 158 meters in 1987. At that level the live storage capacity of the reservoir diminished to 24.6 billion cubic meters and its area to 2735 square kilometers. Figure 3.33 shows the fluctuations of the level and volume of the reservoir. The following table gives the water level at the High Dam, the surface area of the

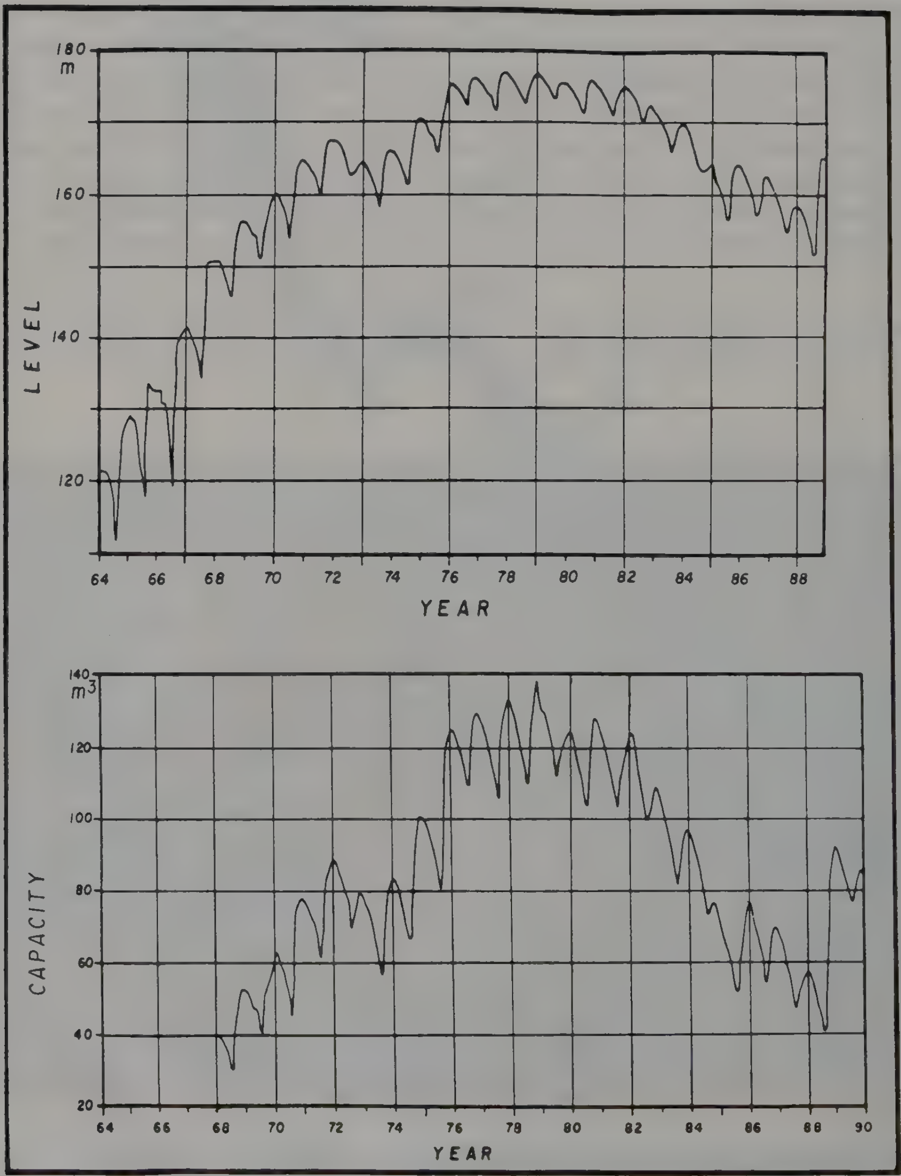

Fig. 3.33. Top, Lake Nasser levels 1964–1988; Bottom, storage capacity 1968–1989.

Year	Water level* (meters asl)	Area km²	Volume 10^9 m³	Live storage 10^9 m³	Releases 10^9 m³	Losses** 10^9 m³
1968	156	2521	50.5	19.4		
1969	161	3067	64.5	33.4		
1970	164	3454	74.3	43.2	54.7	9.3
1971	167	3871	85.3	54.2	55.9	10.7
1972	167	3871	85.3	54.2	55.5	12.4
1973	166	3726	81.5	50.4	56.4	8.0
1974	171	4480	101.9	70.8	56.1	10.8
1975	176	5358	126.5	95.4	54.4	14.2
1976	177	5548	131.9	100.0	54.7	15.0
1977	177	5548	131.9	100.0	57.7	14.6
1978	178	5738	137.5	100.0	61.9	13.9
1979	177	5548	131.9	100.0	59.0	13.1
1980	175	5108	121.3	90.2	56.7	12.8
1981	176	5358	126.5	95.4	58.0	12.9
1982	172	4652	106.4	75.3	59.1	12.5
1983	169	4162	93.3	62.2	57.6	8.4
1984	166	3726	81.5	50.4	57.3	9.7
1985	164	3454	74.3	43.2	55.8	6.4
1986	162	3202	67.6	36.5	55.5	5.7
1987	158	2735	55.7	24.6		
1988	168	4016	89.2	58.1		
1989	169	4162	93.3	62.2		
1990	165	3581	77.9	46.8		

*Highest level usually reached in or around the month of December.
**Includes evaporation and seepage losses.

reservoir, its total volume, live storage capacity, the water released for use in Egypt, and the estimated losses through evaporation and seepage from 1968 to 1990.

4.3.2.4. The operation of the reservoir

The reservoir fulfils multi-purpose roles of water conservation, flood protection and hydropower generation. Releases of water from the High Dam are governed by the 1959 Nile Waters Agreement between Egypt and the Sudan which divides the net benefit of the High Dam between the two countries, whereby 14.5 billion cubic meters per year go to the Sudan and 7.5 billion cubic meters go to Egypt. When these shares are added to their historically established rights, the shares of both countries, after the full operation of the High Dam, rise to 18.5 billion cubic meters for the Sudan and 55.5 billion cubic meters for Egypt per year. The releases from the dam are scheduled primarily to meet irrigation requirements; hydropower is generated as an important secondary benefit. In addition, the reservoir is operated to control the annual flood by drawing down the reservoir to a predetermined level on a specified date each year. A further constraint on the operation of the reservoir is imposed by the necessity to limit the magnitude of releases so as to avoid downstrean degradation and/or hindrance to navigation. It is difficult, especially in years of low inflow, to reconcile irrigation requirements, which vary markedly from season to season, with power demands which tend to be fairly uniform throughout the year. The operation rules for the Aswan High Dam give priority in scheduling

water releases to seasonal irrigation needs and this results, in years of short supply, in the inefficient use of the power-generating plants of the dam.

The operation rules of the High Dam are based on the pioneering work of Hurst (1965); long term fluctuations of the river were taken into consideration to secure a constant flow from the reservoir irrespective of the amount of water carried by the river in a particular year. Many authors attempted to work out the rules which would secure this flow (Hurst, Black & Simaika 1978; Water Master Plan especially papers 14 (1981) & 22 (1983); El-Assiouti, Abou Seida & Dorra (1979); Attia, El-Shirbini & Carr (1979); Attia & Fahmy (1981) and Whittington & Guariso (1983)). The rules are such that actual water needs are released when the floods are "normal". Under no circumstance is the level of the reservoir allowed to exceed 175 meters on July 31. During years of low floods, the water discharged for use in Egypt and the Sudan is reduced according to a sliding scale in order to make sure that the reservoir will not be emptied.

The amount of monthly releases, therefore, is determined by the amount of the flood. Years of very low floods (below 52 billion cubic meters per year) have a monthly release schedule which is different from that of years of low flood (70 billion cubic meters), average flood (90 billion cubic meters), high flood (110 billion cubic meters) and very high flood (more than 110 billion cubic meters). The reservoir is divided, for operational purposes, into several zones. The zone below level 147 meters above sea level is the inactive or dead storage zone which is reserved for the sediment carried by the river into the reservoir and will, therefore, decrease in volume with time. No water is allowed to be released from this zone. The zone between levels 147 and 150 meters is reached in years of abnormally low floods. When the reservoir level falls to this zone it becomes necessary to reduce releases on the basis of a progressively sliding scale (the so-called lower rule curve). The zone between levels 150 and 175 meters meets the current demands of both agriculture and power generation in Egypt and the Sudan and releases are made according to schedule. The zone between levels 175 and 178 meters allows for excess releases and more importantly for water storage that may be used in years of low floods. At present, the reservoir level is not allowed to exceed 178 meters and is provided with a spillway that will lead the excess water into a depression in the Western Desert at Tushka (Fig. 3.34). In its present form the spillway is an ungated canal without a regulator. It was hurriedly excavated in 1979. As stated earlier the original design of the dam allowed the reservoir to reach up to a maximum level of 183 meters; water in excess of this level was to be released to Egypt through an emergency spillway at Aswan. The decision to change the original design and to lower the level of maximum elevation was made to avoid the possible consequences of a very high flood, such as that of 1878 (150 billion cubic meters), if it were to reach the reservoir while it was full. It was feared that the release of the excess sediment-free water into the downstream Nile would increase the rate of scouring of the bed of the river and cause damage to the barrages and bridge foundations. The great effort exerted by a water-starved country to dispose of the additional waters that could come with high floods is paradoxical indeed. According to Whittington & Guariso (1983) there would have been no need to change the original design of the dam and to build the new spillway had the operating policy of the dam been properly implemented.

4.3.2.5. Benefits of the Aswan High Dam

The building of the High Dam blocked the Nile at Aswan, converted the river downstream into a great irrigation canal and gave Egyptian agriculture a secure and regular supply of water in a manner the like of which had not been known before. These benefits as well as many others

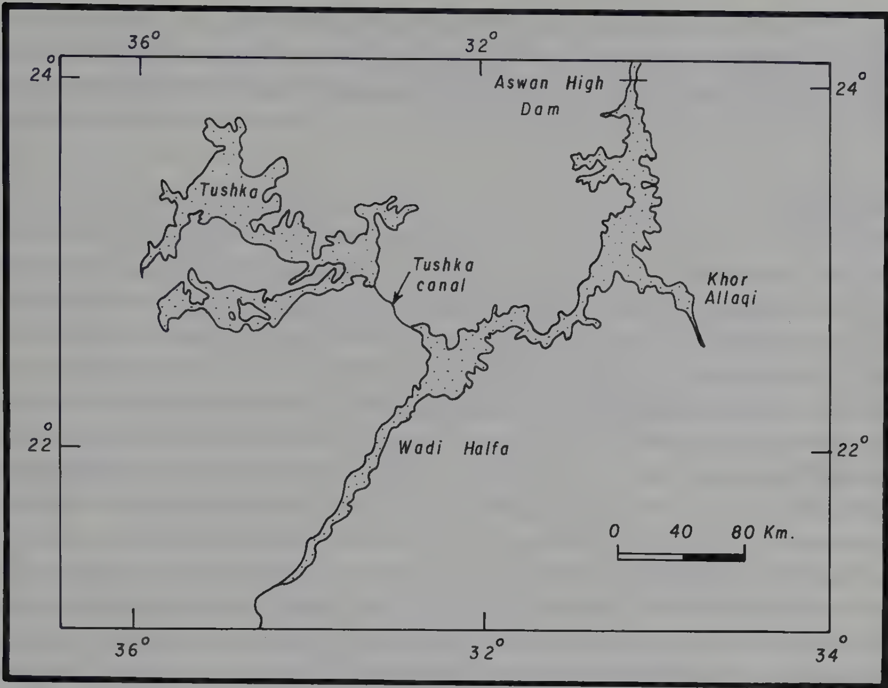

Fig. 3.34. Map of the Tushka depression.

that came with the harnessing of a water resource were accompanied by side effects that left an impact on both the physical and social levels. Like any other daring structure, the High Dam interfered with the course of nature, disturbed its balance and set a new equilibrium to which nature and man had to readjust.

The most obvious benefit of the High Dam was the damming of the water that used to flow into the Mediterranean during and after each flood. It was now trapped behind the dam and made available to Egypt and the Sudan. The quantity of this water averages 32 billion cubic meters per year of which 22 billion are available for use and 10 billion are written off to evaporation and seepage. In addition to this water, the dam trapped and stored the excess waters of the years of high flood to be used in years of low flood. In fact, the dam gave Egypt and the Sudan a water bank which, if properly managed, would supply them with their water requirements when they are needed. The value of the dam in this respect became abundantly clear during the long periods of low flood levels of the 1970's and the 1980's. During most of the years of these two decades Egypt received (after the Sudan abstractions) lesser water than it regularly needed. Had it not been for the dam, Egypt would have suffered from the drought that afflicted many other African states. It would have lost close to one quarter of its agriculture and would have paid an enormous price economically, socially and politically. During the years of low flow Egypt continued to draw more water than its allotment; it never applied the lower rule curve of the operation of the dam. Had it not been for the fact that the Sudan used less than its allotment, by an average of 5 billion cubic meters per year, this disastrous policy would have brought the reservoir to its dead storage level of 30 billion cubic meters by the year 1984, and the reservoir would not have risen above that level even allowing for the large flood of 1988.

The building of the dam protected Egypt from the vagaries of the year to year variations of the Nile flood, ending forever the hazards which high floods had repeatedly and periodically brought to Egypt. This benfit alone would be sufficient justification for the building of the High Dam; it is difficult to conceive of a modern state living under the threat of being entirely washed over.

The regulation of the water supply made possible the conversion to perennial irrigation of the 700,000 feddans of basin irrigation lands, which were used as an escape for the flood waters at their height. The additional water supplied by the building of the dam made possible the launching of expanded programs of land reclamation. Irrigation water was extended to areas beyond the earlier reach of the canals, principally the Nubariya and Salam canals to the west and east of the delta respectively. Although figures are difficult to come by, at least 1.6 million feddans of new lands have been reclaimed and are claimed to have been put under agricultural production during the past 30 years. Of these, some 912,000 feddans were reclaimed in the decade of the 1960's, and since then 747,000 feddans have been reclaimed. Inspite of this great effort there seems to have been no substantial increase in the cultivated area of Egypt (from 5.9 million feddans in 1960 to 6.1 million feddans in 1986). One of the reasons for this is the incessant loss of the old lands to growing urban centers and to commercial and industrial establishments. An estimated 300,000 feddans of the old lands have been lost in this process notwithstanding the government edict of 1984 prohibiting such developments. Another 300,000 feddans of the old lands are estimated to have been stripped of their top soil which was used as raw material for brick making. In addition, a large part of the newly reclaimed lands were so marginal that some were never put to cultivation. Opinions differ as to the viability of many of the reclamation projects. Most of the reclaimed lands are of poor quality and need extensive treatment to obtain moderate yields; and many are irrigated by the traditional and expensive methods of overflooding and/or by lifting water to a great height. Highly critical reports on the land reclamation projects were issued by the USAID and Hunting Services Consulting Office indicating the low productivity of the newly reclaimed lands. Some of the reclaimed land along the Nubariya canal were abandoned on account of waterlogging, and parts of the new pump irrigation schemes in the Tahrir province were never brought to successful cultivation and were abandoned shortly after installation (White 1988). It is estimated that one third of the reclaimed lands of the 1960's did not reach productivity levels.

However, many of the problems which adversely impacted earlier land reclamation have been resolved. Egypt's Land Master Plan includes projects for the reclamation of some 2.8 million feddans (out of 18 million feddans surveyed), using the current Nile water resources (including future savings) by the year 2000 (El-Beltagy 1990). The bulk of the selected lands lies immediately to the east and west of the delta, although additional reclamation sites are located in many other parts. The viability of these proposed land reclamation projects rests upon the success of applying more efficient methods of water convenience and irrigation systems and on the selection of genetically superior plant and crop types more suited to the soils and conditions of the reclaimed land.

With more low season water becoming available to the Sudan, land reclamation in the Sudan progressed during the late 1960's and 1970's. As already stated the expansion of the Gezira scheme (from about one million feddans in 1955 to 2 million feddans in the early 1980's) and the implementation of the Rahad scheme (300,000 feddans) became possible only after the building of the High Dam. In addition, there was the Halfa scheme (300,000 feddans) making use of the stored water of the Khashm el-Girba dam erected on the River Atbara with an original capacity of 1.3 billion cubic meters.

The Aswan High Dam also provided Egypt with a hydroelectric power facility with an installed capacity of 2100 Megawatt electric. This facility which was in operation by 1967 has twelve Francis turbines, two in each of six tunnels. Two turbines are supposed to be stopped in rotation for maintenance. Each turbine has a capacity of 180,000 kilowatt at the design head of 57.5 meters. The station was anticipated to generate a maximum of 10 billion kilowatt/hour annually. In practice, the production of hydropower from the High dam reached about 5 billion kilowatt/hour in 1975, 6 billion kilowatt/hour in 1976, and 7.15 billion kilowatt/hour in 1977. This gradual increase in production was due to more effective use of the water released from the High dam, increased volume of water discharged (about 5 percent in excess of the 55.5 billion cubic meter specified in the 1959 Nile Waters Agreement), and high reservoir levels. Although the annual production level from the High Dam has never reached the anticipated maximum output, the 1977 output constituted 53 percent of the total electric power used in Egypt in that year. Since 1977 the Nile flows have become lower and the discharge bypassing the turbines has been reduced from 27 percent of the total to 13 percent; most of this water was released during the months with high irrigation requirements (May–August). This resulted in a reduction of the power produced from the High Dam. In 1987 it reached 6 billion kilowatt/hour, a 34 percent reduction from 1977, representing less than 18 percent of the total electric power used in Egypt in that year. In the meantime there has been an increase in the use of fossil fuel driven plants in Egypt.

4.3.2.6. Side effects of the Aswan High Dam

(a) In the reservoir area

The most obvious and immediate effects of the Aswan High Dam were felt in the reservoir area where the newly-formed lake inundated forever the strip of land which was the home of close to 400,000 Nubians (Fig. 3.35) and where an array of temples, tombs and fortresses stood.

Fig. 3.35a. Nubia in the process of being inundated.

Egyptian Nubians were evacuated from the fringe of land along the Nile and resettled in the new lands reclaimed in the Kom Ombo plain in Egypt, while Sudanese Nubians were resettled in the Khashm el-Girba development on the River Atbara in the Sudan. Inspite of the emotional difficulties of leaving home, the resettlement program was voluntarily carried out and was in many ways a success. There was ample compensation and the promise of improved material conditions and better social services. Twenty years after their relocation the Nubians enjoy improved conditions with regard to health, schooling opportunities and material standards. No doubt there were many things that they must have missed such as the considerably larger and more gracious homes left behind and the serene and beautiful landscape dominated by the river, the palm tree and the golden sands of the desert. The impact of the dam on the Nubian population is the subject of many works (e.g. Fahim 1982).

The imminent flooding of the many temples, tombs and fortresses along the Nubian stretch of the river gave rise to an international effort to save these unparalleled archeological treasures. The process of the destruction of these monuments started with the second heightening of the old Aswan dam in 1912 when the resulting reservoir flooded most of the sites and most of the temples as far south as (but not including) Abu Simbel. During the summer flood, the sluices of the old dam were opened and the waters of the reservoir were allowed to pour through to bring the annual inundation to the land of Egypt; it was then that the submerged temples reappeared out of the waters. A later heightening of the dam brought further losses of ancient sites; but the building of the Aswan High Dam threatened the total loss of all these monuments below the waters of the permanent lake. This threat led to what was undoubtedly the greatest of international campaigns to save the monuments of Nubia. Many archeological institutes sent missions to identify the sites and record them for posterity; 23 missions from 25 countries undertook extensive surveys. The best review of the activities of the international campaign to save the monuments of Nubia can be found in the February–March 1980 issue of the UNESCO Courier, including articles by some of the eminent archeologists who participated in the project: W. Y. Adams, T. Save-Söderbergh, J. Vercoutter and R. A. Fernea. Every kind of surviving site was investigated; the region was surveyed for unidentified settlements; careful records were made of all inscriptions, formal and informal (including graffiti), carved or scratched on rocks. All the free-standing temples and other ancient buildings capable of being moved were transferred to new sites on higher ground or even sent abroad as gifts to countries that had been especially generous in their help. The Kalabsha, Beit el-Wali and Qertassi temples (see Fig. 3.32 for locations) were all moved to higher ground at a site to the south of Aswan. The El-Moharaqqa, El-Sebu and El-Dakka temples were moved to higher ground in El-Sebu area. The Roman temple of Dandur, which later had become a church, was sent to the United States where it now stands in the Metropolitan Museum, New York. The temple of El-Derr was dismantled and moved to Philae.

The salvage of the rock-cut temples of Abu Simbel, which started in 1969, was a monumental feat in both its engineering and financing. The $40 million program was financed, in part, by an international fund set up by UNESCO, with the Egyptian Government paying about half the cost. To move these giant temples engineers cut away rock around them, leaving only a shell. Stone-cutters sawed the rock into 20- and 30-ton slabs which were lifted up by cranes and transported to the top of the hill. They were then reassembled in front of an artificially-built mound whose weight was born by a huge arch of steel. Figure 3.36 shows the old location of the temples under Lake Nasser and their new cliff-top site. Another monumental accomplishment was the moving of the Philae temples to the higher island of Agilkia in 1979. As at Abu Simbel,

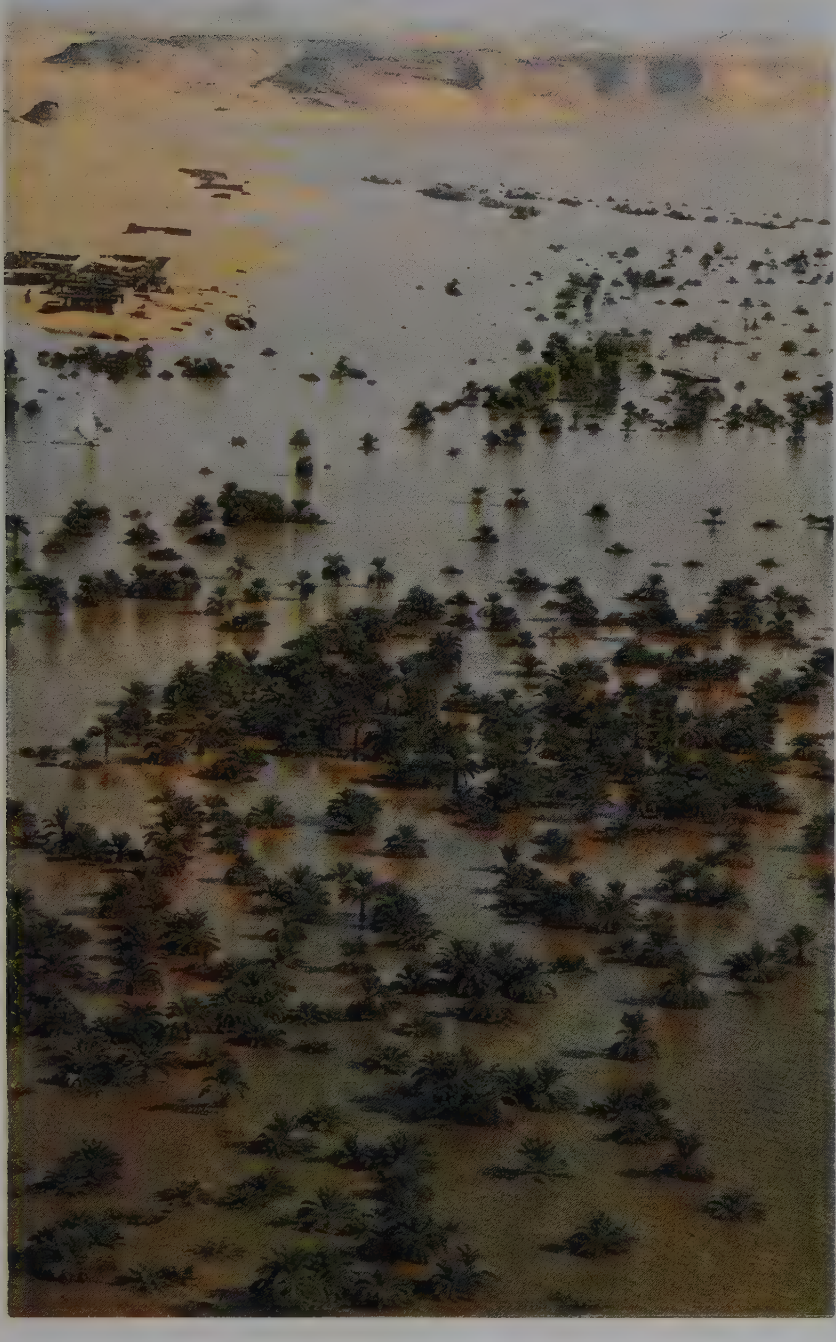

Fig. 3.35b. Nubia in the process of being inundated.

Fig. 3.36. Painting by National Geographic Society artist Robert W. Nicholson showing the old location of temples under Lake Nasser and their new cliff-top site (from National Geographic Society 1966. The River Nile).

a coffer dam was constructed around the island; once the water had been pumped out, the carvings and inscriptions on the buildings were recorded by photogrammetry, preparatory to the dismantling and reerection of the temple complex on the neighboring island of Agilkia. The program was conducted under the auspices of UNESCO and the funding came from the Egyptian Government and the proceeds of the Tutankhamun Exhibitions that were touring the world in the 1970's.

In the reservoir itself the quality of the stored water became different from that of a running river. The new water body of Lake Nasser developed its own physical and chemical environment. The lake is poorly mixed and exhibits a distinct stratification pattern most of the year; the stratification is different in the khors from that in the main channel. In May the reservoir stratifies. At the onset of the flood season in late July the stratification starts to be destroyed. This destruction starts at the southern end of the reservoir and does not seem to reach the northern parts. This results in variations in oxygen concentrations with the season; an oxygenated surface layer is deepest in the southern part of the lake and most shallow at the northern part close to the dam. The turbidity of the flood waters is greater in the southern parts of the lake. Evaporation in this poorly mixed lake results in a 10 to 15 percent increase in the total dissolved solids of the water depending on the surface area of the lake. This new environment affects the pattern of development of the plankton and fish population. A survey of Lake Nasser's characteristics with regard to temperature, dissolved oxygen content, transparency, wind patterns, conductivity, water chemistry and biological activity is given in Entz (1976). Phytoplankton and zooplankton distribution in Lake Nasser exhibits seasonal variations in its different parts. In the northern part

the undesirable blue-green algae, Cyanophyta, is predominant. In addition to being capable of nitrogen fixation and constituting a dead end in the food chain it causes taste and odor problems. Fortunately, much of this odor is washed out immediately after the water is released as it rushes through the swift stretch of the Aswan cataract area. An environmental monitoring program was carried out in Lake Nasser and the Nile downstream of Aswan in the 1970's, and is reported upon in Mancy & Hafez (1979).

The creation of the new water body of Lake Nasser provided both Egypt and the Sudan with new fishing grounds. The average catch of fish increased from 2600 metric tons in 1968 to 22,500 metric tons in 1978 to 34,000 metric tons in 1987. It is not clear whether this increase in catch was due to increased productivity of the lake or to increased fishing activity by private and cooperative fishing enterprises. It is extremely doubtful that these rates can be maintained.

The reservoir margins underwent some ecological changes as the shore vegetation became seasonal. Plans to establish agriculture around the reservoir shores are temporarily on hold. As the pilot plots near Abu Simbel have shown, it is difficult to reclaim these lands. Not only do they have poor desert soils but they are also subject to the huge annual water level fluctuations of the reservoir. In addition, there is growing concern that the introduction of agriculture along the banks of the lake could affect the water quality of the reservoir. A further consideration that favors keeping the reservoir margins a natural reserve free from human activities is the need to maintain them as a buffer between the African tropics and the Mediterranean belt. There is the risk that if the area were to be inhabited, several African diseases and pests could invade Egypt and become endemic. As an example mention is made of the Gambian mosquito which invaded Egypt on several occasions, the last being in 1942.

An important concern that came with the building of the High Dam was the effect it could induce on the stability of the earth's crust in the Nubian region. An early study carried out during the construction of the dam concluded that the safety of the dam would not be impaired if tremors were to occur. This study preceded the setting up by UNESCO of a "Working Group on Seismic Phenomena Associated with Large Reservoirs" which deliberated in its meetings (UNESCO 1970 and 1971), the effects of the impounding of water in reservoirs on seismic phenomena. The Group came to the conclusion that "in the present state of knowledge regarding the seismic effects associated with reservoir loading, it is impossible to predict with certainty whether hazardous earthquakes are likely to be triggered by the filling of a large reservoir".

There was great concern in Egypt after the November 14, 1981 major shock (with a magnitude of 5.3 on the Richter scale) which affected the Kalabsha area (60 kilometers to the southwest of Aswan, in the Lake Nasser area). This led to an intensive study of the seismicity of the region and the establishment of a seismic net in the entire lake area. After canvassing a large number of possible seismic events, the study concluded that the dam would remain stable in the face of the most severe earthquake that the area might be expected to suffer. The quake was attributed to tectonic activity (Woodward-Clyde Consultants 1986 & Kebeasy, Maamoun & Ibrahim 1981).

(b) In the downstream river

i. Channel degradation and silt deprivation

The Aswan High Dam prevents the sediment which the Nile carries every year from reaching its destination in the fields of Egypt or the Mediterranean Sea. The entire load of this sediment

was entrapped behind the dam after the damming of the Nile in 1964. It started to fill up the "dead storage" capacity of the reservoir which was reserved for the purpose of receiving the sediment load of the river for the following 408 years (Gasser 1979; Makary 1983 & Egypt Water Master Plan 1981). The life expectancy of the dead storage zone was based on the assumption that the river would carry in the future a yearly amount of sediment equal to what it had carried in the past and that the sediment would be deposited evenly along the bed of the reservoir. Results of field studies, however, showed that the sediment load that entered the reservoir was not evenly distributed on the bed of the reservoir; most of the sediment was deposited in the vicinity of the second cataract where it reached a thickness of 25 meters in 1977 (Fig. 3.37). A progressive decrease in the thickness of the sediment occurred to the north and was reduced to less than one meter in the region of Abu Simbel. Northward of this point there was hardly any sediment deposition. Interestingly large areas of the second cataract have now been fully filled and lie above the flood level forming islands of considerable dimensions. According to the High Dam authorities the volume of the sediment in the Dal Cataract–Abu Simbel stretch in the period 1978–1990 amounted to 1.42 billion cubic meters which had accumulated at an average rate of 109 million cubic meters per year.

With the sediment charges of the river entrapped behind the dam, the river downstream became almost sediment-free. It was feared that this drastic change in the regimen of the river would release the energy which was dissipated in carrying the sediment, causing it to scour the bed of the river and erode its banks. Estimates differed greatly as to the rate at which the river bed would be scoured. An excellent review of the different views of the earlier workers, Ali Fathi, Gamal Moustafa and Hammad Youssef is given in Abu el-Ata (1978). Fathi and Moustafa predicted extremely high rates which actual observation has proved totally unrealistic. Youssef predicted that the degradation of the bed of the river would almost stop once it is covered with coarse materials after the removal of the finer part of the silt; the bed of the river would then act as a natural armor. Actual practice has shown that the rate of scouring is directly proportional to the amount of water released from the dam. If the release is kept within the range of 230 million cubic meters of water during the peak season, then the rate would be minimal and the damage contained. The greatest damage was expected to occur in the barrage areas. After 1966 the river bed was lowered at an annual rate of 2.2 centimeters in the 117-kilometer Aswan–Esna reach, 3 centimeters in the 194-kilometer Esna–Naga Hammadi reach, 2.5 centimeters in the 167-kilometer Naga Hammadi–Assiut reach and less than half a centimeter in the 350-kilometer Assiut–Cairo reach. In the mid 1980's stable conditions were reached and the rates of erosion have almost stopped. The annual range of today's agricultural needs is 153 million cubic meters per day and a maximum daily peak of 230 million cubic meters. The stark reality that comes out of this very delicate balance is that the present Nile channel does not allow for greater releases, and unless there is a total revamping of the downstream water control structures there will always be a limit to the amount of water that Egypt can utilize. One plausible solution to overcome this problem would be to build a series of weirs downstream of each of the existing three barrages to reduce the river's velocity and another barrage possibly between Aswan and Esna.

Prior to the building of the dam there were many who feared that the silt-free waters of the Nile which have less nutritients would adversely affect the fertility of the land. This argument may have some truth in the case of the 700,000 feddans which were still under basin irrigation in 1963 and which used to receive the bulk of the silt, but it cannot hold for the majority of the

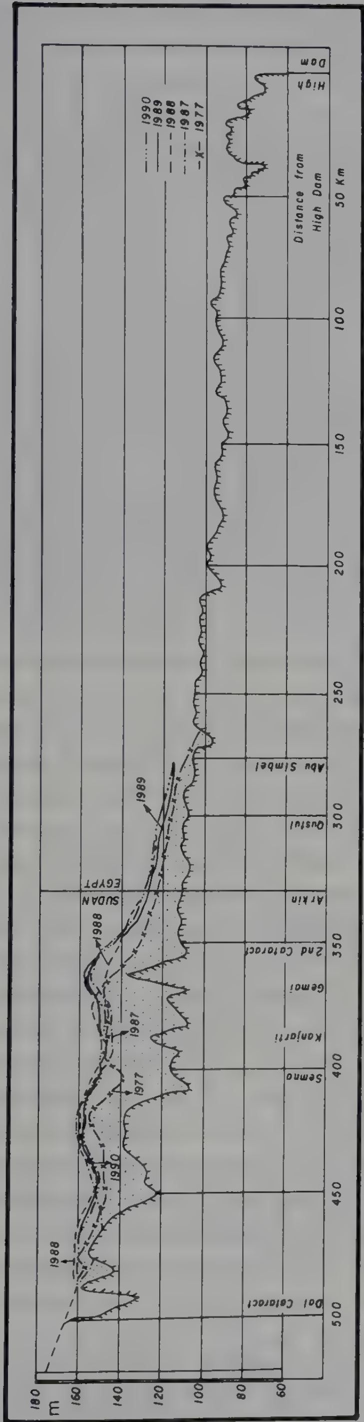

Fig. 3.37. Profile of Lake Nasser from Dal Cataract to Aswan showing areas of silt accumulation.

lands which were perennially irrigated and which received hardly any silt. Most of the silt that used to come with the Nile flood past Cairo was flushed to the sea with the exception of about 10 percent which went into the delta lands. The total amount of nutrients contained in this amount of silt was so small that its value for the plant was considered nil or minimal at best. Whatever opinion one may hold, the truth of the matter is that the introduction of perennial agriculture and intensive cropping methods, which took place long before the building of the dam, reduced the value of the Nile silt as a source for nutrients. The silt is estimated to have a total nitrogen content of about 0.0013 percent of its total weight of which less than one third was released as food to the plant. Because of the low nitrogen content of the silt Egypt had relied heavily on chemical fertilizers long before the High Dam was built.

The total loss of the silt deprived Egypt of a basic and historic raw material for its brick industry. As late as the early 1980's there were at least 7000 brick kilns scattered along the Nile with a total production of more than one billion bricks a year. With their raw material gone and having no other brick to use, the construction sector was so pressed for the silt brick that for several years the brick manufacturers furnished their kilns with topsoil which they used to buy from the farmers at premium prices. This resulted in the loss of land at an estimated annual rate of 30,000 feddans for the decade ending in 1985 (White 1988, after Kishk 1986).

ii. Dune accumulation

Wind driven sands from the large fetches of the Western Desert are deposited on the flood plain and the river bed itself especially during the dust storms of the *khamsin*. Before the building of the High Dam most of the sand that was deposited on the bed of the river was flushed out into the Mediterranean Sea by the annual flood of the river. On the other hand, the sand which accumulated over the western banks of the river was ordinarily inundated by the flood waters and was incorporated into the sediments of the river. At times of low floods and extraordinary aridity, however, the dune and wind-driven sands remained uncovered slowly encroaching on the flood plain of the river and forming dune fields of great areal extent over the western bank. Witness to these fields can be seen in the Khefoug landscape in the middle latitudes of Egypt (believed to have been formed in historical time during the First Intermediate Period of Pharaonic Egypt at the end of the Holocene Wet Phase, see Part II) and also in the numerous sand heaps that used to cover the cliffs of Nubia and the valley, masking many of the temples of upper Egypt and Nubia. A case in question is the Abu Simbel temple which was totally under sand in 1819 at the time of the visit of Belzoni (Fig. 3.38). With the building of the dam, the large amounts of sand driven by the wind into the river in the Nubian stretch will no longer be flushed out but will accumulate year after year in the Nasser lake, contributing to the filling of the dead storage of the reservoir. Unfortunately, there are no studies on this phenomenon, the quantity of sand accumulating every year or the long term effect of this accumulation on the capacity of the reservoir. A preliminary study of the satellite images of the region of the second cataract shows a large number of sand dunes affecting the reservoir region in a most marked way.

iii. Coastal erosion

Many authors feared that the coasts of Egypt would suffer accelerated erosion after the building of the High Dam and the ceasing of the arrival of the silt which was carried into the Mediterranean during flood time. The silt was distributed along the coast line and reworked and dispersed during the following winter season by wind, currents and other agents. A large part

Fig. 3.38. Abu Simbel area in 1820 showing sand covering the temples, from Belzoni, 1820.

of the fine silt-clay grade of the Nile flood sediments was transported to the Levantine basin by the surface currents generated by the water circulation system, while the bulk of the flood discharge was dispersed by the longshore currents which were generated by the oblique waves hitting the coast producing an eastward flow and a lateral drift of the sand as far as the Palestinian coastline (Sharaf El-Din 1973). Large amounts of sand were also removed from the beaches by the offshore winds building up extensive dunes along the coast. Estimates of sand losses are in the order of 200,000 cubic meters per annum west of the Rosetta mouth and 400,0000 cubic meters per annum west of the Damietta mouth (Sestini 1989; UNESCO/UNDP report on the Nile delta 1976). The retreat of the Mediterranean coast line since the beginning of the twentieth century instigated an intense program of systematic data gathering of the shore line processes, the so-called "Coastal Erosion Project" which was initiated in 1971. The project was jointly carried out by the Institute of Oceanography and Fisheries, the Egyptian Academy of Scientific Research and the UNESCO as a technical executive agency for the UNDP. Since the termination of the program in 1978 coastal research has become the responsibility of the Coastal Research Institute at the Ministry of Public Works and Water Resources. The institute carries out on a regular basis hydrographic surveys of the coastal zone from Alexandria to El-Arish where water depths are measured along a large number of profiles at frequent distances in order to establish a bathymetric map and to monitor the changes that affect the zone. It also conducts current measurements (longshore currents, currents beyond the breaker zone), records sea level variations at Rosetta, Burullus, Ras el-Barr, el-Arish, determines the salinity and temperature and records the wave characteristics in several locations along the coast (Fanos 1989).

The factors which influence coastal erosion in Egypt are not fully understood. Many authors blame the Nile control irrigation schemes, which deprived the coasts from the silt, for the coastal

retreat (Kassas 1972). In the opinion of this author the problem goes beyond sediment supply. We have already seen in Part I that the quantity of silt contributed by the modern Nile since its start did not form a significant part of the bulk of the delta nor was it responsible for its progradation. The bulk of the delta is a remnant of an older and considerably larger delta which was built long before the modern Nile came into existence. The amount of sediment that the modern Nile deposited over this core and during the millenia of its history seems to have been very small. The thickness of the modern Nile's silt layers on both the surface and the offshore slopes of the delta is comparatively small (see discussion in Part I). It is, therefore, difficult to accept the view that the cessation of the arrival of this small amount of silt could have materially affected the delta coast line. If the irrigation schemes had any influence in this regard, it would be that they diverted to the sea a larger part of the sediment that used to go to the basin lands in the valley and delta. The schemes would have added to rather than substracted from the amount of silt that went into the sea. The present author, therefore, advances the idea that the most important single factor which has determined the shape of the delta and the configuration of its shoreline has been the fluctuations in global sea level. It is possible to relate the recent retreat of the shoreline of the delta along most of its frontier in recent historical time to the global rise of the sea level which accompanied the end of the Little Ice Age of Europe in the middle of the nineteenth century. Historical documents indicate that the delta extended between 5 to 8 kilometers into the sea during the seventeenth to nineteenth centuries when numerous Turkish forts, which are now totally under water, were built. If the sea level continues to rise, as many scientists believe that it will under the influence of the so-called global warming trend, then the delta, large parts of which stand only 1 to 2 meters above sea level, will be inundated. A mere one meter rise in the sea level would inundate the peripheral lakes and large stretches of the overcrowded northern delta region and would lead to increased sea water seepage into the delta aquifer. The present Shore Protection Master Plan including walls, groins and revetted quays at key points along the Mediterranean coast does not take into consideration any substantial rise in the sea level. However, this would be a global problem that Egypt will not face alone.

Silt deprivation, however, seems to have had an adverse effect on the fisheries of Egypt. In the eastern Mediterranean, sardine fishery declined to a trickle from previous catches of about 18,000 tons. Many authors assume that this decline is related to the disappearance of the nutrient-rich Nile silt although the decline was going on prior to the building of the dam and was assumed then to be due to over-fishing (Ibrahim & Soliman 1982).

iv. The increased use of pesticides and fertilizers

The introduction of perennial agriculture at the beginning of the twentieth century made possible the intensive use of the land and the universalization of triennial cropping. Initially there was a higher average yield per unit of land. Like every innovation this did not occur without a price. In the first place, wet agriculture increased moisture in both soil and atmosphere and produced an ecologically favorable habitat for plant and animal parasites to proliferate. There was a marked and sudden increase in pests which necessitated the use of insecticides which were virtually unknown during basin irrigation times. The quantity of imported insecticides soared from 2143 metric tons in 1952/1953 to 12,550 metric tons in 1962/1963 to 15,462 metric tons in 1983/1984. In addition, the use of fungicides and herbicides increased from 886 and 82 tons respectively in 1969 to 8862 and 933 respectively in 1980 (Abdel-Gawad 1985).

Perennial cultivation and intensive cropping diminished the natural fertility of the land. To counter this, chemical fetilizers were used in increasing quantities. Fertilizer consumption increased from 46 kilograms per feddan in 1961–1965 to 70 kilograms in 1974–1976 to 103 kilograms in 1981 to 147 kilograms in 1987. In the meantime crop yields per unit area became among the highest in the world. The average cereal production per feddan in 1984–1986 increased to 1880 kilograms, an increase of 26 percent from 1964–1966. The index of agricultural production increased from 100 in 1964–1966 to 137 in 1979–1981 to 155 in 1984–1986. Part of the increase in production was due to the introduction of high-yielding and improved varieties of cereals. Close to 64 percent of the maize production in 1986 was by improved varieties.

v. Rise of the water table and the problems of drainage

Waterlogging and an increase in salinity were other consequences of perennial irrigation. The continuous watering of the land prevented the natural downward drainage that took place in the basin irrigation system during the period of low water. The increase in the number of irrigations per year and the reduction in the number of days when the canals were closed for cleaning and rehabilitation, from 21 to 7 days, resulted in the rise of the subsoil water, threatening crop roots with asphyxiation. After the building of the Aswan High Dam and the total control of the flood the problem became more acute. The use of water for irrigation increased because of the horizontal expansion in agricultural land areas, the increase in areas with crops requiring higher water applications such as sugar cane and rice and the increased cropping intensities. Prior to the building of the High Dam, irrigation water reaching the fields was in the range of 20 to 23 billion cubic meters of which about 50 percent was drainage water. After the building of the dam the amount of water going to the fields increased to about 32 to 34 billion cubic meters of which about 50 percent went into the subsoil as drainage water. In addition, the groundwater table became stable as the wave which used to come with each flood, raising the groundwater table, disappeared (Abu Zeid 1987).

There was also a simultaneous increase in the salinity of the soil. Under the system of basin irrigation the salts carried by the waters of the Nile were flushed into the sea by the annual flood; now they started to accumulate on the land and sink in the ground. It is estimated that about 96 kilograms of salt are deposited on each feddan per year (Hamdan 1961).

The Nile delta ground water aquifer suffers from the intrusion of seawater, but authors differ as to the extent of that intrusion. It is anywhere from 30 to 130 kilometers from the sea. The salinity map prepared by the Research Institute of Ground water (RIGW), Egyptian Ministry of Public Works (and reproduced in Abu Zeid 1987), shows that the aquifer beneath the northern reaches of the delta (up to 15 to 35 kilometers inland from the sea) has a salinity which is equal to that of the sea (35,000 parts per million (ppm)) if not more. In fact, salinities of up to 45,000 ppm are recorded for the coastal areas. The brackish water zone (10,000 ppm of dissolved solids) lies away from the Mediterranean coast at a distance of 25 to 55 kilometers inland.

Recent work (Bahr, Moser, Baumann & Arlt, personal communication) shows that most of the delta aquifer has fresh water concentration (less than 1000 ppm of dissolved solids) and that the brackish water zone is about 30 kilometers inland from the sea (Fig. 3.39). Salt water intrusion is less active than was previously assumed and Egypt can indeed depend on its ground

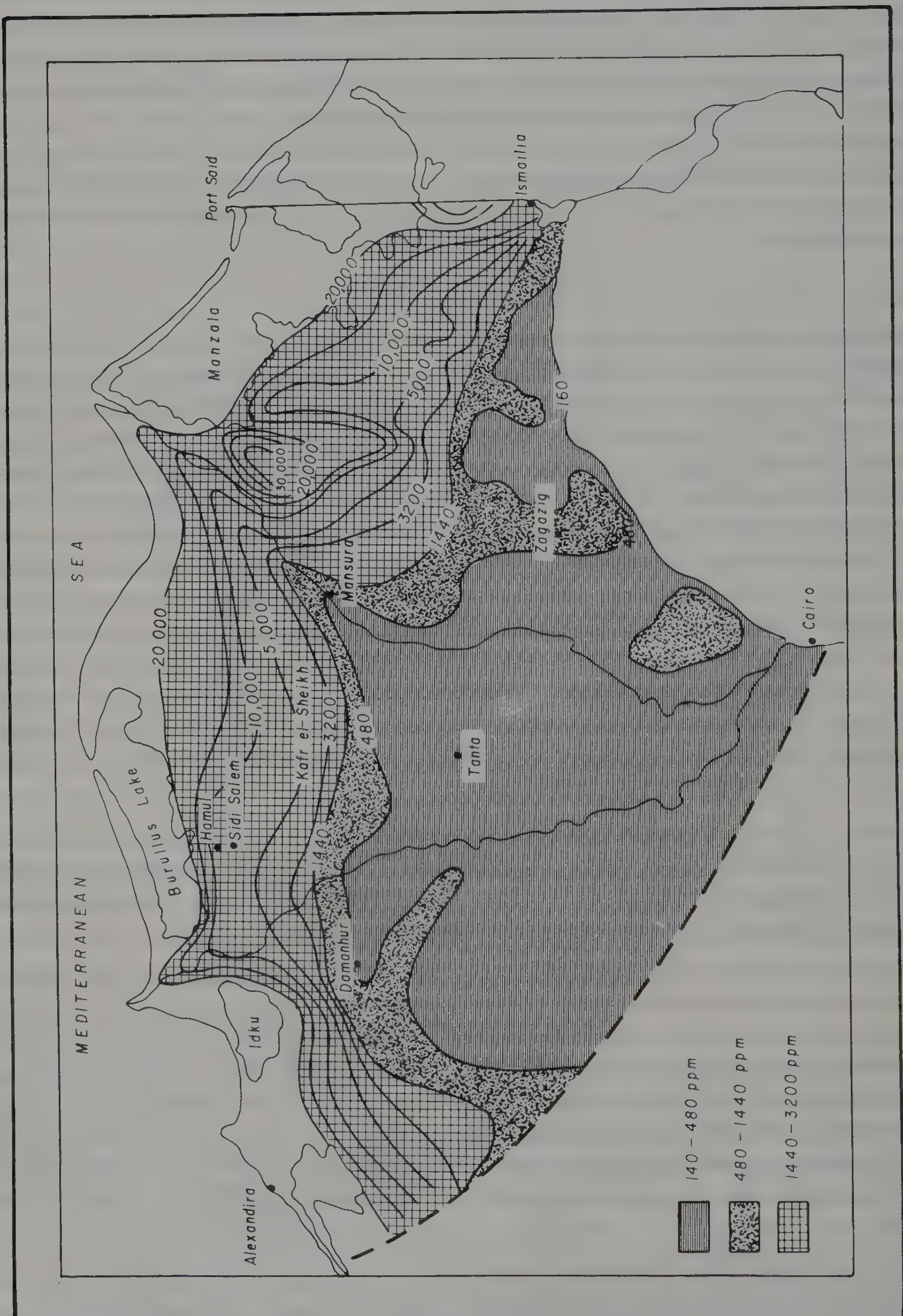

Fig. 3.39. Groundwater salinity map of the delta (in ppm of total dissolved solids).

water aquifer beneath the delta without fear of sea water intrusion. The aquifer beneath the delta is enormous, many times larger than the High Dam, and is rechargeable (Research Institute for Ground Water (RIGW) 1988).

vi. Changes in water quality

The water quality in the Nile downstream from Aswan has changed dramatically as the Nile waters became silt-free, less turbid and with considerably less velocity. Turbidity dropped from 30–3000 milligrams per liter (with the highest level at the time of the incoming flood) to 15–40 milligrams per liter. The total dissolved solids increased from 110–180 milligrams per liter to 120–230 milligrams per liter, with a similar change in the pattern of seasonal variation. The density of the phytoplankton increased from an average of 160–250 milligrams per liter. There is a higher count of undesirable algae in the regulated flows of the river causing odor and taste problems which require increased prechlorination and special water treatment (White 1988).

There is evidence that the downstream river is becoming a receptacle of domestic, industrial and agricultural waste and that its environment is deteriorating. Agricultural return flows that drain into the river are upward from 15 billion cubic meters. The municipalities and the majority of industrial centers discharge their waste into the river. Conditions in the delta are even worse because of the reduced velocity of the river, concentration of industrial plants and more intense agriculture. The waste from the industrial complex of Kafr el-Zayat (on the Rosetta branch) and Talkha (on the Damietta branch) has caused deterioration of the environment and septic conditions near the mouths of these branches.

Measurements recorded in the four monitoring stations along the Nile (Khartoum (the Sudan), Aswan, Cairo and Damietta mouth at Farskour) clearly show the progressive deterioration of the river as one travels northward. In 1980 the electrical conductivity (a measure of salinity) increased from 197 in Khartoum to 245 in Aswan to 285 in Cairo to 410 in Farskour (S/cm). Dissolved chlorine increased from 15 milligrams per liter in Khartoum to 47 milligrams per liter in Farskour. The ammonia which registered zero in all three southern stations increased to 1.3 milligram per liter in Farskour. Biochemical Oxygen Demand (BOD) caused by wastewater inputs is minimal in the southern two stations and extremely high in Cairo (3.2 milligrams per liter) and in Farskour (10 milligrams per liter), far above the accepted level of 2 milligrams per liter.

The deterioration has affected the fish population in the downstream Nile. Many of the 47 commercial species which inhabited the river in 1948 have disappeared. Only 17 species now exist in the commercial catch in upper Egypt. Northward from Assiut the river's environment starts to deteriorate at a fast rate; the number of species of fish, and in particular the commercially desirable species become fewer. Only 17 species are present in Assiut of which *Tilapia nilotica* constitutes about 60 percent of the total catch. The species are reduced to 13 in the Cairo area of which *Tilapia nilotica* composes 66 percent of the total catch. Further north in the Damietta branch only 11 species are represented of which *Tilapia nilotica* composes 83 percent of the catch. North of Zifta on the Damietta branch, *Clarias* predominates (85 percent) and *Tilapia nilotica* declines to 10 percent (Mancy & Hafez 1979).

In conclusion, it can be stated that the Aswan High Dam, like any other enormous structure, has interfered with nature's course and has changed the face of the river and the land of Egypt

and the Sudan. It has converted the river into a great canal carrying silt-free water in quantities which are solely determined by man. The benefits that this structure has brought to Egypt became quite obvious in the years of successive low flows of the Nile during the 1980's which could have afflicted Egypt in the same manner they afflicted other less fortunate African states. In addition to providing Egypt with a water bank that it can use the way it sees fit, it has freed Egypt from the fear of being inundated by the high floods that used to periodically breach its dikes and threaten its fields and towns; it has given it and the Sudan the water that has made possible the expansion of their agriculture both in a vertical and horizontal manner. The High Dam has also improved navigation on the downstream waterway system by eliminating low flows in some canals and swift currents and high levels during flood seasons. It has also given Egypt power production that has been transmitted to remote areas that had never seen electricity before.

Like all major structures interfering with the balance of nature the High Dam has also had side effects many of which were anticipated and became obvious with time; others may yet be in store. Most of the observed effects are, in fact, universal and current to all nations which, in their pursuit of material comfort, have intruded on nature and changed its balance whether by building water control structures or industrial plants. When the dam was conceived all consultants and commissions appointed by the Egyptian government or by international organisations to study the High Dam recommended its building and considered its benefits to outweigh by far its disadvantages. There was no exception in this regard. The list included experts from the United States, Germany, the Soviet Union and the World Bank. The few critics who were against the building of the dam were not against the control of the river but were against the choice of the site or alarmed by certain effects that, in fact, did not occur. Problems such as the preservation of the top soil, the prevention of pollution, the guarding of water quality and the efficient management of flows to watch against river degradation and scouring are problems that the Egyptians have to deal with if they want to make full use of the waters of the Nile, increase their wealth and meet the demands and expectations of their growing population.

4.4. Crops of the Perennial Irrigation System

Perennial irrigation gave Egypt a wide range of winter, summer and *nili* (flood) crops. The major winter crops remain clover and wheat as they were under the system of basin irrigation. The major summer crops are maize (introduced from Syria), cotton and rice. Their value increased and their cultivation was encouraged under the system of perennial irrigation. *Nili* crops include rice, maize, sorghum and onions among others. Three crops of vegetables are grown in one year, winter from November to March, summer from April to July and *nili* from August to October. Secondary crops include beans, lentils and onions in the winter and groundnuts and sesame among others in the summer. The value of certain traditional crops such as flax and indigo declined under the system of perennial irrigation due to the increased use of cotton and the import of aniline.

The crops are rotated under a complex system (Fig. 3.40). A typical rotation would start with a short crop of clover, or catch crop during the winter, followed by a cotton crop which would be harvested in September–October. In the following winter, wheat would be planted followed by a summer crop of rice, maize, or sorghum. Wheat and maize may be grown in the third year before returning to the cultivation of cotton. Fruits and sugarcane occupy the land for several years. Until recently the crop mix in any one area was determined largely by the government.

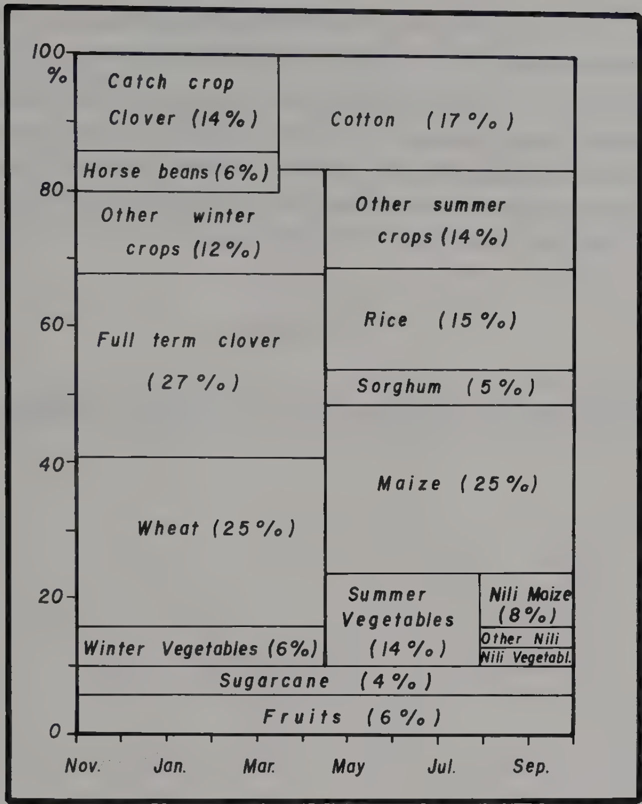

Fig. 3.40. Areas devoted to different crops in Egypt, 1988.

This was done to allocate water efficiently in the amount and at the time most suited for that mix and also to guarantee the cultivation of certain crops that form the basic raw materials of certain industries or that are important for export. Procurement quotas were imposed on these crops. Since 1987 the government has been attempting to apply a policy to liberalize agriculture, lift government controls on the type of crop cultivated in any one area and cancel procurement quotas. However, in the case of cotton and sugarcane, which make the basic raw materials for the immense textile and sugar industries, it has not been possible to lift the procurement quotas.

The areas cultivating different crops have changed over the years. For a long time and until the 1970's cotton and catch crop clover (or any other winter crop) rotation occupied about 28 percent of the land. In the 1980's that rotation was reduced to about 17 percent. There was a reduction in the value of cotton exports from close to 10 percent of the total commodity exports of Egypt in 1976 to 3 percent in 1986. The rice, maize, sorghum summer mix was also reduced from about 56 percent of the land to about 45 percent in the 1980's. This was done in favor of non traditional crops which have come to be cherished by the farmer. Vegetables and fruits increased at a fast rate. Summer vegetables, which occupied about 0.6 percent of the land area in 1976, soared to 1.6 percent in 1988. In 1989 the areas occupied by the different crops were (in thousands of feddans): wheat 1533, *bersim* (full term) 1756, *bersim* (catch crop) 1000, cotton 1014, maize (summer and *nili*) 1960, sorghum (summer) 314, rice 840, beans 330, lentils 17,

flax 41, sugarcane 270, peanuts 30 and sesame 30. Winter vegetables occupied 350,000 feddans, while summer and *nili* vegetables occupied each 180,000 feddans.

In 1988 agriculture in Egypt accounted for 20 percent of the gross domestic product (estimated to be about 54 billion pounds in 1988/1989) and 35 percent of employment. The share of agricultural exports decreased from 14 percent in 1978 to 9 percent in 1988. It is worth noting that the value of agricultural exports which amounted to 356 million pounds in 1988 contributed about 9 percent of the food import bill of the same year.

PART IV

THE FUTURE USES OF THE WATERS OF THE NILE

1

AGREEMENTS PERTAINING TO THE WATERS OF THE NILE

1.1. Historical

In our discussion of the utilization of the waters of the Nile, we saw that until the beginning of the twentieth century, Egypt was the only basin state that had made use of the waters of the Nile. Until then Egypt's right to use that water had not been challenged and the question of the division of the waters of the Nile among the basin states had never been raised. The Nile was indeed the river of Egypt; the country depended on it for its very existence. All other basin states depended on dry agriculture and herding; the river played a secondary role. Save for a few scattered farming communities in Nubia and Ethiopia, which had little if any effect on the flow of the river, the river had no farmers living on its banks or depending on its waters.

From the earliest of times the Egyptians felt secure about their Nile water supply and their foreign policy concentrated on the defence of their borders against possible raids from the south. It was only during the nineteenth century that this traditional policy was abandoned and replaced by a more aggressive policy aimed at securing the sources of the Nile and making sure that they did not fall into the hands of the European powers which had started competing for the division of Africa during that century. Egyptian forces were sent to achieve that goal. By 1875 they had conquered Darfur, annexed Harrar and the Somali ports overlooking the Gulf of Aden and had extended their power southward to the equatorial lakes; almost the whole of the Nile Basin was in their hands.

In the meantime Britain, France and Portugal had started their exploits in Africa. Britain had conquered southern Africa and penetrated parts of the western coasts of the continent. These incursions were met with resistance prompting the British Parliament in 1854 to ask the government to stop its campaigns in Africa. Until 1875 the size of the British possessions in Africa did not exceed 640,000 square kilometers some of which had been purchased from Denmark and some had been exchanged with Holland against lands in Sumatra and southeast Asia. Britain also exercised a strong influence in Zanzibar which had been separated from Muscat by the governor of India in 1861. France had appropriated a small part of the North African coast in Algiers, Senegal, Guinea coast, the Gulf of Gabon and some areas on the southern coast of the Red Sea. The Portuguese meanwhile had appropriated land that did not exceed 100,000 square kilometers.

In the 1870's the European powers were involved in a heated competition to conquer and divide the African continent among themselves. Germany joined the race after her victory in the 1870 war with France. At the same time France began settling and colonizing parts of north

Africa. Italy went into Eritrea. The king of Belgium, who was intrigued by the discoveries of Livingstone and Stanley in the Congo basin, decided to send an expedition to occupy that basin. The success of the expedition aroused the concern of the European powers who feared that this might encourage individual adventurers. This led them to expedite the apportionment of the African continent among themselves. For years after that Africa became the scene of intrigue and military exploits. Portugal occupied Angola and Mozambique, Germany Tanganyika and the Cameroon and Britain the Niger basin and then the Nile Basin.

In November 1884 the colonial powers met at a conference in Berlin to determine and outline their spheres of influence in Africa. The conference was attended by Germany, Austria, Belgium, Denmark, Spain, the United States, France, Britain, Italy, Holland, Portugal, Russia, Sweden, Norway and Turkey. In a series of acts, protocols, agreements, treatises, declarations, and exchanges of notes, which were collected in three volumes by Hertslet (1967), the spheres of influence of the different powers were delineated. These delineations became the boundaries of many of the African states as we know them today. The occupation of Egypt by Britain in 1882 was not favorably regarded and was not recognized by other European powers; Egypt remained, at least from the legal point of view, part of the Turkish Empire. France had hoped Egypt would be part of her share but had to give up this hope after the failure of her Expedition to the White Nile at Fashoda in March 1899. In return, Britain recognized France's hegemony over the African Sahel (previously known as the French Sudan). Thus the final settlement led to the exclusion of Egypt from Africa and its fall and almost all of its empire in the hands of Britain.

1.2. The Agreements

The delineation of the spheres of influence helped ease tensions and normalize relations among the colonial powers. Britain began to delineate the boundaries of the lands it had acquired by contracting agreements with the neighboring powers. The following are some of the agreements which mention the waters of the Nile (Egypt's Ministry of Foreign Affairs 1983).

(1) A protocol with Italy for the demarcation of their respective spheres of influence in eastern Africa signed in Rome on April 15, 1891. Article three of this protocol specifies that "the Italian Government shall undertake not to initiate any irrigation works on the Atbara which may alter the rate of flow of the Nile". This was followed by an exchange of notes between Italy and Britain signed in Rome on November 22, 1901 marking the frontier between the Anglo-Egyptian Sudan and Eritrea.

(2) A treaty with Ethiopia for the demarcation of the frontiers between the Anglo-Egyptian Sudan and Ethiopia signed in Addis Ababa on May 15, 1902. Article three of this agreement reads as follows "His Majesty Emperor Menelik, King of Kings of Ethiopia, shall undertake, before the Government of Her British Majesty, not to construct and authorize the construction of any structures on the Blue Nile, Lake Tana or Sobat which would have the effect of obstructing the flow of their waters into the Nile, except in agreement with the Government of Her British Majesty and the Government of Sudan".

(3) An agreement between Great Britain, France and Italy respecting Ethiopia signed in London on December 13, 1906. In article I of this agreement the three powers decided to cooperate in maintaining the political and territorial *status quo* in Ethiopia as determined by the state of affairs then existing and in article IV to concert together in order to safeguard the interests of Great Britain and Egypt in the Nile Basin and "more especially, with regard to the

control of the waters of this river and its tributaries (the consideration due to them being given to local interests)".

(4) An agreement between His Majesty King Leopold II, the king of the Independent State of Congo, and His Majesty Edward VII, the King of the United Kingdom of Great Britain and Ireland, and of the British Dominions beyond the Seas, Emperor of India, signed in London on May 12, 1894 redefining their spheres of influence in Central Africa. Article three of the Agreement provides that "The Government of the Independent State of Congo undertake not to construct, or allow the construction of structures on the Semliki or the Isango, or nearby, which would reduce the volume of water entering Lake Albert except with the consent of the Sudanese Government".

With the sealing of these agreements the cotton farms of Egypt, which supplied the British textile industry with its raw material, were assured of their water supply.

These agreements, inherited from an age past, are the only standing agreements which regulate the rivers emanating from Ethiopia and the Congo. For Egypt they are still valid (Ahmed 1990) irrespective of the fact that they were signed by European colonial powers acting on behalf of the countries concerned. The Organisation of African Unity (OAU) also recognizes the validity of these and other agreements which deal with the demarcation of the frontiers and national borders of the newly independent states of Africa, for fear that any tampering with them would open a Pandora's box. Egypt and most African states accept the principle confirmed by the Vienna Convention of 1978 about State Succession and Treaties that territorial status agreements constitute an obligation to the contracting parties' territory and are unaffected by changes of sovereignty or governments. For Ethiopia the agreements are nul and void at least with regard to the constraints they impose on the use of its rivers (Tilahun 1979; Abate 1990). Its government has declared its intention to use the waters of the rivers emanating from its territory as it sees fit. Repeated declarations by the Government of Ethiopia and its representatives in various international forums have asserted the policy of that government to reserve its sovereign right to use the waters of the Ethiopian rivers unilaterallay if no accord by the downstream neighbors on the equitable utilization of the waters of the Nile is reached (Waterbury 1982). According to their view the principle of state succession does not apply when it relates to the sovereignty of the state on its natural resources. Furthermore, it is claimed that the agreement signed by the King of Ethiopia in 1902 was of a temporary nature (Caponera 1959).

The subject of cooperation with Ethiopia has been of great concern to the successive governments of Egypt and the Sudan since the beginning of the twentieth century and the inception of the schemes for century storage. This cooperation never materialized inspite of numerous efforts. In 1925 a mediation effort was made by Italy to the Ethiopian Government on behalf of Britain, representing the Sudan, to allow the building of a dam on Lake Tana in return for a promise from Britain to intervene with the Ethiopian Government, on behalf of Italy, to allow the building of a railway line connecting the Italian colonies of Eritrea and Somalia via Ethiopia. In the 1930's another attempt was made when the Ethiopian Government allowed an Egyptian–Sudanese mission to survey Lake Tana and to look into the possibilities of building a dam on the lake. In 1935 and as a result of the survey the governments of Egypt and the Sudan presented a proposal to the government of Ethiopia to build a dam on the lake at their own expense. The proposal was the subject of lengthy negotiations and was finally refused 10 years

after it had been presented. It was said then that the project did not give priority to the generation of electricity which was of primary interest to Ethiopia.

Save for the successful agreements which Egypt contracted with the Sudan and which we shall deal with in a special section, Egypt has not been able to sign any agreement with any other basin state with the exception of Uganda. In 1954 Egypt and Britain acting on behalf of Uganda signed an agreement regarding the building of the Owen dam at the exit of Lake Victoria. The dam was proposed by the Government of Uganda for the generation of electricity. In its note dated 19 January 1949 Uganda assured Egypt that "the construction and operation of this electric power station shall not be prejudicial to the interests of Egypt, either through the reduction in the quantity of water flowing into Egypt or through the change in the date on its flow into Egypt or even through the drop in its level". In its reply on 5 February 1949, the Egyptian Government stated that the building of the dam was consistent with its long range water projects which called for the use of Lake Victoria as a reservoir. In order that the dam may serve both irrigation needs in Egypt and electric generation in Uganda, Egypt suggested raising the level of the reservoir one additional meter, the expenses of which were to be incurred by the Egyptian Government. The British Government agreed to the proposal in its note dated 5 January 1953. The dam was finished in 1954 and has been functioning well since then; there have been no serious objections from any party as to the operation of the dam.

1.3. Agreements Between Egypt and the Sudan

Prior to the great expansion in cotton farming in the Sudan in the 1920's Egypt had authorized the Government of the Sudan to pump from the Nile the amount of water needed to increase the area of cotton cultivation from 2000 to 10,000 feddans in 1904 and to 20,000 feddans in 1909. In addition, Egypt had agreed to an unlimited use of the flood waters for irrigation in the high season between July 15 and February 28. In 1919 the area under cotton cultivation in the Sudan was less than 20,000 feddans. In the 1920's that area increased dramatically and plans were underway for the enlargement of the Gezira project in the Sudan to 300,000 feddans. The entry of the Sudan as a major user of the Nile waters alarmed the Egyptian authorities who commissioned the Nile Control Department to conduct a survey of the effects of this expansion on Egypt. The results of the survey were embodied in Sir Murdoch McDonald's report (1920). The report stated that the water requirements of both Egypt and the Sudan could be satisfied. The total needs of Egypt and the Sudan were estimated to be 56 billion cubic meters, of which 34 billion cubic meters were during the July–December season and 22 during the January–June (timely) season. The Sudan's share of this estimate was 4 billion cubic meters in the flood season and 2 billion cubic meters in the timely season. Since these quantities were larger than the storage capacity available, several projects aimed at dealing with this shortage were suggested, including, among others, the Sennar reservoir on the Blue Nile to provide water for the Gezira project, and the Gebel Aulia Dam on the White Nile to provide timely water for Egypt. The survey and proposals were sharply criticized in Egypt with the result that the Egyptian Government in 1920 appointed the Nile Projects Commission to study the matter. The Commission was composed of a nominee of the Government of India as chairman, a nominee of the University of Cambridge in England, and a nominee of the Government of the United States. The Commission was charged to "give the Egyptian Government its opinion on the projects....with a view to the further regulation of the annual supply to the benefit of Egypt and the Sudan and...to report upon the propriety of the manner in which, as a result of these projects,

the increased supply of available water provided by them will be allocated at each stage of development from Egypt and the Sudan" (Garretson 1967). The Commission endorsed the proposals to construct the Gezira scheme and granted that Egypt had the right to "a supply of water sufficient to irrigate an area equal to the largest area which has been irrigated in any single year since the Aswan Dam in its present form was completed, and that Egypt has an established claim to receive this water at the particular seasons when it is required". The Commission further added that the largest area which Egypt could thus claim would be 5 million feddans, which was the area under cultivation in 1916–1917. This meant that Egypt would receive the entire discharge of the Nile in the low season, leaving the Sudan to meet its requirements from the flood. The Sudan's right to irrigation water for the irrigation of the 300,000 feddans was recognized although no annual amount was fixed because of lack of data as to past water consumption in the Sudan.

There was dissention in the commission with regard to the future allocation of the waters as they would be needed by the various projects. Mr. T. H. Cory, the nominee of the United States Government, submitted a separate report in which he proposed that the as yet unassigned waters should be divided between Egypt and the Sudan not according to present or future population needs but according to the prospective cultivable lands in each country. The Indian and British members, however, objected that this proposal would be "impossible to apply in the present circumstances".

The conclusions of the Commission met with great resistance in Egypt and the Egyptian Government shelved the report. This did not please the Sudan. In the wake of the Egyptian–Sudanese crisis precipitated by the assassination of the Governor of the Sudan (the Sirdar) in Cairo in May 1924, the British High Commissioner in Egypt revived old fears by threatening to go ahead with the plans of expanding the areas of cotton cultivation in the Gezira scheme in the Sudan "to an unlimited figure as need may arise" unless the Egyptian Government appointed an international commission to look into the matter of the apportionment of the waters of the Nile. The Egyptian Government responded by appointing the Nile Projects Commission in January 1925 "for the purpose of examining and proposing the basis on which irrigation (in the Sudan) can be carried out with full consideration of the interests of Egypt and without detriment to her natural and historic rights". The Commission, chaired by a Dutch engineer Mr. Canter Cremers, included Abdel Hamid Soliman from Egypt and R. M. McGregor from Britain. Their recommendations provided the basis for the Nile Waters Agreement of 7 May, 1929. The Agreement took the form of an exchange of notes incorporating the notes and findings of the 1925 Commission as an integral part of the Agreement. It admitted the right of the Sudan to agricultural expansion but stipulated that any increase in the use of the Nile waters in the Sudan would be such not to "infringe Egypt's natural and historical rights in the waters of the Nile". It apportioned the waters so that Egypt and the Sudan would receive enough water to irrigate the lands under cultivation at the time of the Agreement; this was estimated to be 48 billion cubic meters for Egypt and 4 billion cubic meters for the Sudan.

The 1929 Agreement was very sensitive to the irrigation requirements of Egypt, and was written to accomodate these requirements with those of the Sudan as they had developed in the mid 1920's. Egypt was given the right to veto any upstream irrigation works, empowered to undertake works upstream without the consent of the Sudan and given the right to inspect Sudanese installations in order to assure that the distribution of water was carried in accordance

with the Agreement. No wonder that the Sudan, upon gaining independence in January 1956, declared that it did not consider itself bound by the 1929 Agreement. All this was changed in the Agreement of 1959 which was negotiated during the period when the High Dam was being considered. The right of the Sudan to construct the Roseiris dam and other works deemed necessary for exploiting its share was granted and the management of the Agreement was relegated to a joint technical Commission made up of an equal number of technicians from each side. The net benefits of the High Dam were alloted in the ratio of 14.5 billion cubic meters to the Sudan and 7.5 billion cubic meters to Egypt. This calculation was based on an estimate of the mean natural river discharge at Aswan of 84 billion and the High Dam reservoir loss of about 10 billion. These allotments when added to the shares of Egypt and the Sudan according to the 1929 Agreement made Egypt's share 55.5 billion cubic meters and the Sudan 18.5 billion cubic meters.

The Joint Permanent Technical Commission was given a wide range of functions including the elaboration of projects aimed at increasing the output of the Nile, the supervision of the execution of works approved by the two Governments and the development and application of rules of operation of irrigation works. An important element of the Agreement was that the two countries pledged to examine together any request from any basin state for a portion of the waters of the Nile, and "if it results from this examination that a part of the waters of the Nile should be granted to one or the other of the said States, the quantity accepted shall be deducted from the share of the two republics in equal proportions".

The Joint Permanent Technical Commission has held regular meetings in Cairo and Khartoum since 1959 and has achieved excellent results including, among others, the planning and supervision of the digging of the Jonglei Canal described in section 4.3.1, Part III.

1.4. The Law of International Drainage Basins

At present, the law governing international drainage basins is in the form of general rules that were put forth by the International Law Association and adopted in Helsinki in the summer of 1966. The rules are published in Garretson, Hayton & Olmstead (1967, pages 779–833). Most states accept the rules which fall in six chapters and 47 articles of which chapters two and six are of relevance to our discussion. Chapter two deals with the equitable utilization of the waters of an international drainage basin while Chapter six deals with procedures for the prevention and settlement of disputes.

Chapter two elaborates on the key principle of international law that every basin state in an international drainage basin has the right to an equitable share of the waters of the drainage basin. It rejects the unlimited sovereignty position spelled out by the "Harmon Doctrine" which supports the unqualified right of a state to utilize and dispose of the waters of an international river flowing through its territory. Among the relevant factors which the rules list for determining the "equitable" share each basin state is entitled to are: the extent of the drainage area in its territory; its contribution of water to the river system; the past utilization of the waters of the basin, including in particular the existing utilization; the economic and social needs; the comparative costs of alternative means; the availability of other resources; the avoidance of unnecessary waste in the utilization of waters of the basin and finally the degree to which the needs of a basin state may be satisfied without causing substantial injury to a co-basin state. There is no concensus as to the interpretation of these factors or the weight that should be given

to each of them. Some believe that the equitable distribution of the waters of an international river should be made according to the agricultural potential of each basin state rather than the number of people who are making use of the waters of the river. This difference of opinion was voiced when Egypt and the Sudan were negotiating the 1929 Water Agreement.

Chapter six of the rules relates to the procedures for the prevention and settlement of international disputes as to the legal rights or other interests of basin states and other states in the waters of an international drainage basin. It emphasizes the obligation of all states to settle their disputes peacefully consistent with the Charter of the United Nations. With a view to preventing disputes from arising among basin states as to their legal rights or other interests, it is recommended that each basin state furnish relevant information to the other basin states concerning the waters of a drainage basin within its territory and, in particular, any proposed constructions or installations which would alter the regime of the basin. This would permit other states to assess their impact and enter into negotiations or appeal to arbitration.

In practice, the Helsinki rules are shoved aside by most states inspite of pledges of adherence. Many upstream states divert or limit the flow of the rivers emanating from their territories without consulting with their neighbors or taking heed of the rules. Examples can be found in the diversion of the Lauca River by Chile, an act which prompted Bolivia, the downstream state, to break diplomatic relations; in the damming of the Euphrates River by Turkey, a move which exacerbated the already high tensions among the riparian states of that river; and in the usurpation of the waters of the Jordan River by Israel, the downstream state, and the channelling of the waters of the river to its reservoirs.

1.5. The Present State of the Nile Water Agreements

It is clear from the above discussion that there are no agreements between the upstream and the downstream states which regulate, monitor or divide the waters of the Nile among them. Save for the agreements between Egypt and the Sudan, the two downstream states, practically all other agreements are old and were entered into by colonial powers on behalf of the basin states; they were promulgated in a totally different atmosphere and a bygone world order. It is indeed difficult to conceive that an independent state would accept to have its sovereignty on its rivers curtailed as stipulated in these agreements (Okidi 1990, 1991). Many of the upstream states have already informed both Egypt and the Sudan that they will not abide by any of these agreements. Among the first acts that Tanganyika (Tanzania) took as it gained its independence in 1962 was the rescinding of any obligations stipulated in any agreements that Britain had entered into with regard to the waters of the Nile. In a note sent to Egypt, the Sudan and Britain Tanganyika asserted its sovereignty over its lakes and rivers and mentioned, in particular, that it considered what came in Article 4 (ii) of the 1929 Water Agreement between Egypt and the Sudan null and void. This article stipulated that "except without prior consent of the Egyptian Government, no irrigation works shall be undertaken nor electric generators installed along the Nile and its branches nor on the lakes from which they flow if these lakes are situated in the Sudan or in countries under British administration which could jeopardize the interests of Egypt either by reducing the quantity of water flowing into Egypt or appreciably changing the date of its flow or causing its level to drop".

Most upstream states object to the 1959 Water Agreement between Egypt and the Sudan. Ethiopia has protested that the Aswan High Dam was built without prior consultation. A note

sent to the Egyptian Ministry of Foreign Affairs on 23 September 1959 stated that a basin state which was planning to build a structure with dimensions of the High Dam should have informed and consulted with other basin states. In another note dated 8 February, 1976 it objected to the diversion of any water of the Nile outside its basin. The note was alluding to the plan of Egypt announced in 1976 to divert water to Sinai by a Canal (el-Salam) that would take off from the Damietta branch of the delta to Sinai passing through a tunnel under the Suez Canal to be dug at el-Tina (25 kilometers south of Port Said on the Ismailia road). This note was followed by another dated 5 May 1980 protesting the plans announced by the President of Egypt to channel part of the Nile water to Israel. Ten years after this note of protest the el-Salam Canal is almost ready for use; and if the intention of the canal is to irrigate lands in northwestern Sinai, as is repeatedly stated by officials of the Egyptian Ministry of Water Resources, then the water of the Nile is not being diverted outside its basin. These lands were reached formerly by the Pelusiac branch of the delta. Joyce Starr, however, wrote in the Christian Science Monitor on 27 May 1992 that the canal is planned to go beyond the basin of the Nile to the Gaza strip. Starr is well connected and is occupied with the issue of water scarcity in the Middle East; she co-authored a book on the subject with Daniel Stoll which was published by the Center for Strategic and International Studies in Washington D.C. (1988).

It is not our intention to discuss the legality of the agreements and actions of the different states with regard to the waters of the Nile. We have already seen that International Law was ineffective in solving problems of lesser magnitude and that it did not deter states from going ahead with plans which denied their co-basin states their "equitable" share of the water of an international river. We only want to emphasize the fact that the division of the waters of the Nile as practiced today is upheld only to the extent of the strategic and economic weight of the beneficiary states. The truth of the matter is that there is not a single upstream state at present which is able to challenge the existing practice, tamper with the waters of the Nile or dam the river in any way. None of these states has the economic muscle or technical know-how to build dams, dig diversion canals or carry a large scale land reclamation operation. None of these states is in a position to mobilize world public opinion, donor countries or international financial institutions to finance such projects. All economic indicators point to the fact that the states have sagging economies and that their populations are increasing at a considerably faster rate than their economies. In the past 40 years populations have increased between two and a half to four times while the Gross National Products have remained very small and have not grown at a rate to cope with the increase in population (Table I).

All the basin states are indebted to the outside world and their budgets have large deficits. All have increased their external and national debts during the past 15 years to more than three times their value, so much so that the service of the debts consumes the larger part of the total exports.

In addition to these economic and fiscal difficulties most basin states have had to cope with the poverty and stress wrought by the drought of the 1970's and 1980's which affected the livelihood of large segments of their populations. They also have had to cope with the political problems arising from the spread of separatist movements resulting from tribal , ethnic and religious tensions. These have contributed to the weakening of central governments, the pervasiveness of corruption and the spending of large sums of money on armaments and instruments of repression. In the Sudan, close to one half of government spending goes to these items alone.

Table I: Population and the Gross National Product of some Nile Basin States*

	Population			Gross National Product (GNP)		Foreign Aid
	(millions)		Annual increase %	Total (million $) (1989)	Per capita Income $	% of GNP
	1950	1990				
Egypt	20.3	52.4	2.6	32,500	620	6
Sudan	9.2	25.2	2.9	13,220	524	1.3
Ethiopia	19.5	49.2	2.4	5950	120	2.1
Kenya	6.3	24.0	3.6	8785	366	7.2
Tanzania	7.9	27.3	2.9	3080	112	10.1
Uganda	4.8	18.8	2.9	4254	226	7.4

*All data are from the World Resources Institute 1992-1993 handbook. The GNP and the per capita income are in U.S. dollars and are converted from local currencies using a three-year average exchange rate. The strong appreciation of the U.S. dollar against other currencies during the last three years may mask the real value of the GNP and the per capita income in some countries. The GNP figures do not take into consideration the destruction or depletion of the natural resources or cultural monuments of the countries. The GNP and per capita income are not adjusted to inflation or to a base year.

A glance at Table II shows that all social indicators point to low standards with regard to health, education and quality of life in general.

If the GNP of the different basin states were to be adjusted to inflation it would be clear that the per capita income had decreased during the past decade. In the Sudan the per capita income went down from 720 dollars in 1977 to less than 70 dollars in 1987; and in Egypt it went down from 610 dollars to 380 dollars during the same period according to the World Bank's Development Report, World Tables, 1988–1989 Edition (published for the World Bank by The Johns Hopkins University Press, Baltimore & London).

Table II: Quality of Life in some Nile Basin States in comparison with some industrialized states

	Per capita protein consumption grams/day 1989	Life expectancy at birth (years) 1990	Infant death rate (deaths/1000 live births) 1990	Adult Iliteracy male & female (%) 1990	Energy consumption per capita gigajoules 1989
Egypt	84	61.6	57	51.5	22
Sudan	58	51.8	99	72.5	2
Ethiopia	51	47	122	?	1
Kenya	59	61	64	30.5	3
Tanzania	49	55	97	67	1
Uganda	48	53	94	51.5	1
United States	111	76.4	8	1	295
Europe	103	75.3	11	2	127

In spite of the fact that at present there seems to be no imminent threat to the flow of the waters of the Nile to Egypt and the Sudan, the two downstream basin states realize that the subject of the division of the waters of the Nile among basin states will eventually be raised in the future. Both countries work closely together, uphold the terms of the 1959 Water Agreement and make sure that the work of the Joint Permanent Technical Commission, established under the terms of the Agreement, proceed smoothly and remain unaffected by political differences. So far the work of the Commission has been very successful. Because the Sudan had not fully used its share of the waters of the Nile, alloted to it under the Agreement, the division of the water during the drought years of the 1970's and 1980's between Egypt and the Sudan was considerably easier than if the Sudan had used its share fully; the real test is yet to come.

The policies of Egypt and the Sudan with regard to their relationships with the upstream basin states are slowly and subtly beginning to diverge. Egypt's policy revolves around building a consensus among basin states in the hope that this would allow the beginning of a dialogue and the establishment of a vehicle through which they would cooperate to develop the basin for the benefit of all. In pursuance of this aim Egypt has initiated, encouraged and participated in every activity common to the basin states. It played a significant role in instigating the hydrometeorological study of the equatorial lakes after the sudden rise of their levels in the early 1960's. It encouraged the upstream states to work together on this study. This effort led to the establishment of the Hydromet Project which was financed by the UNDP and executed by the World Meteorological Organisation (WMO).

The adoption of the "Plan of Action for the Economic Development of Africa" by the organisation of African Unity (OAU) in Lagos in 1980 and the commitment taken "to establish national, subregional and regional institutions which will facilitate the attainment of objectives of self-reliance and self-sustainment" offered an opportunity to Egypt to invite the Nile Basin states to a meeting in Khartoum in 1983, with the purpose of creating a regional grouping. The meeting which was attended by Egypt, Sudan, Uganda, Zaire and the Central African Republic created an informal grouping which it called the UNDUGU (a Swahili word meaning brotherhood). Rwanda and Burundi joined the grouping later and Tanzania participated in its last meeting held in Addis Ababa in 1990. The UNDUGU invited representatives from the UNDP to study the possibilities of the development of the Nile Basin for the benfit of all. These representatives outlined a long-range plan that would increase agricultural lands and establish an electricity grid that would join the Nile Basin states from Enga in Zaire to Aswan in Egypt and possibly beyond. The plan is designed to meet the needs of the expected increase in population and the demographic movements to the cities in the coming 50 years. A preliminary estimate of the cost of this project is between 40 and 60 billion dollars.

Lately the Sudan seems to have been drifting away from this policy and to have been following an agenda of its own. Although this agenda is not yet overt, it can be gleaned from the recent attempts of the Sudan to strengthen its ties with Ethiopia in order to make use of their water resources for their mutual benefit and to create a Sudan–Ethiopia axis that would counter the Egyptian claims. The change in regime in Ethiopia in 1990 gave an impetus to this policy. The Sudan is also seeking a regional grouping of the African Sahel states to counter its isolation. It is obvious that the wing which considers that the 1959 Water Agreement with Egypt was unfair to the Sudan and that its share of the waters of the Nile should be larger has the upper hand in modern Sudanese politics.

2

PRESENT AND FUTURE LAND AND WATER USE IN THE NILE BASIN STATES

In discussing the utilization of the water of the Nile in Part III, we considered its use only in agriculture and neglected other uses such as in industry and for domestic purposes. This was justified in view of the fact that consumption in these latter activities is extremely small and plays an insignificant role in the water balance of the river. The basin states withdraw about 78 billion cubic meters of water from the Nile every year of which 69 billion cubic meters, or close to 88 percent of the total, are used in agriculture. Of these Egypt alone uses 71 percent and the Sudan 23 percent. All other basin states use 6 percent of that water. The basin states use about 9.4 percent of the total amount of water withdrawn from the river for domestic use and 2.4 percent for industry, mainly for cooling thermo-electric generators.

This pattern of water use is totally different from that of the industrialized states. In the United States the percentages of water used in agriculture, industry and for domestic purposes are 33, 54 and 13 percent respectively of total water withdrawals. In Europe the percentages are 35, 38 and 27 percent respectively.

With the exception of Egypt irrigated agriculture does not play an important role in the life of any other basin state. In Egypt the irrigated lands amount to a total of 5.7 million hectars (of which 5.1 million are old lands and 0.6 million are under reclamation) representing more than 73 percent of the total irrigated lands in the entire Nile Basin. The Sudan irrigates another 1.8 million hectars or 23 percent of the total irrigated lands, while all other basin states irrigate about 0.3 million hectars or about 4 percent of that total. Most basin states depend on dry agriculture where close to 38 million hectars of land in the Nile Basin are fit for that type of agriculture. About one third of that land lies in the Sudan, another third in Ethiopia and a third in the other basin states. Many of the basin states also depend on herding and cattle breeding; about 215 million hectars can be used for this important activity. Of these about 45 percent lie in the Sudan, 20 percent in Ethiopia, 18 percent in Kenya, 16 percent in Tanzania and less than one percent in Uganda. Table III gives the land areas and their uses in the different basin states.

Agriculture is the main economic activity of most basin states and is the occupation of a large part of the labor force. The percentage of this to the total labor force differs from one state to another. It is about 86 percent of the total labor force in Uganda and Tanzania and about 46 percent in Egypt. This force does not contribute to the economy a share proportionate to its size. In Egypt agriculture contributes only about 21 percent of the total Gross Domestic Product (GDP). In Uganda and Tanzania it contributes about 65 and 73 percent respectively. Table IV gives the size of the labor force in some Nile Basin states and its distribution in the different

Table III: Land Areas and Use in Some Nile Basin States (all land areas are in thousand hectars)

	Area	Cropland	Irrigated land (% to total cropland)	Permanent pasture	Forest	Other land*
Egypt	99,545	5700	5600 (98%)	—	31	96,943
Sudan	23,7500	12,499	1750 (14%)	98,000	45,440	79377
Ethiopia	110,100	13,930	140 (1%)	45,000	27,300	23,870
Kenya	56,969	2424	49 (2%)	38,100	2380	14,065
Tanzania	88,604	5240	104 (2%)	35,000	41,180	7184
Uganda	19,955	6705	—	1800	5660	5790

*Includes deserts, grassland not used for pasture, built-on areas, wetlands, wastelands and roads.

Table IV: Size of labor force in some Nile Basin states and its contribution to GDP (1989)

	Labor force (10^3)	Labor Force in (%)			Distribution of GDP (%)		
		Agriculture	Industry	Services	Agriculture	Industry	Services
Egypt	14,600	46	20	34	21	25	54
Sudan	8100	71	8	21	36	14	50
Ethiopia	21,250	80	8	12	43	17	40
Kenya	10,000	81	7	12	31	19	50
Tanzania	12,600	86	5	9	65	8	27
Uganda	8125	86	4	10	73	7	20
U.S.A.	122,000	4	31	65	2	29	69
Europe	231,700	14	39	47	6	36	58

economic activities. The table also includes the equivalent figures for the United States and Europe for comparison.

The average yield of an irrigated feddan in Egypt is about 850 dollars and in the Sudan about 650 dollars. A feddan of dry agriculture yields about 60 dollars in Ethiopia, 400 dollars in Kenya and about 150 dollars in Tanzania.

At present, the waters of the Nile are divided among the basin states proportionally to the area of irrigated lands in each state. This pattern of distribution is under pressure because of the plans of most basin states to forsake dry agriculture in favor of irrigated agriculture. Pressure also comes from the expected increase of population which will double during the coming three decades, as well as from the expected mass migration to the banks of the river.

Such migrations have already occurred on a large scale due not only to the appeal of the settled life along the banks of the river but also to the devastating effect of the drought that ravaged the Sahel region in the 1970's and 1980's and forced many who depended on dry

agriculture and/or herding to the banks of the river. In times past these semi-nomadic farmers followed the rain during times of drought and resettled wherever it fell in the Sahel. This became increasingly difficult when free movement became hard as a result of the establishment in the Sahel region of several states with guarded borders that required entry permits. A further factor which inhibited free movement was added when the Sahel region became the scene of civil wars and tribal conflicts and the route of contraband trade of goods and arms. This affected the life of the Sahel inhabitants which, inspite of offering bare subsistence, was not without rewards. It was a free life unfettered by boundaries and offering space, serenity and a clean environment. Now these inhabitants have no other choice, when faced with drought, but to move to the banks of the river and to try to make a living by irrigated agriculture. Up to the mid twentieth century the Sahel was a total wilderness which was devoid of any development. Today about 58 percent of its area has some evidence of settlement such as roads, buildings, railroads, airports, pipelines, power lines and reservoirs. All of this took place between 1960 and 1990.(1)

There were population movements from areas of dry irrigation to the banks of the river as well as migrations to cities whose populations swelled enormously. This is most evident in the upstream states. Between 1960 and 1990 urban populations in Tanzania increased sevenfold from 4.7 percent to 32.8 percent. In Kenya the increase was threefold from 7.4 to 23.6 percent and in the Sudan from 10.3 to 22 percent.

These substantial demographic changes have put pressure on the Nile Basin states to increase food production and turn to the Nile as an important source of the water needed for agricultural expansion. This continuing and increasing pressure on the waters of the Nile forms the subject of studies of Allan (1990), Beaumont & McLachlan (1985), Collins (1990), Kashef (1981), Naff & Matson (1984), Said (1986), Starr (1983), Starr & Stoll (1988), Waterbury (1979, 1982), Whittington & Haynes (1985) and others.

In the following paragraphs an attempt is made to summarize the present-day patterns of the use of the waters of the Nile in the different Nile Basin states as well as their future plans for the use of these waters.

2.1. Egypt and the Master Water Plan

Egypt is and will remain for a long time to come the main beneficiary of the waters of the Nile, for the river is the primary source of its water relative to which all other sources are negligible. The rainfall is minimal and the water that can be extracted in a sustainable manner from the underground water reservoirs that lie beneath a large part of its surface area is very small when compared to Egypt's water needs. The largest of these groundwater reservoirs lies beneath the Western Desert; less important reservoirs are in northern Sinai and in many of the wadi mouths of the Eastern Desert and southern Sinai. The extensive reservoir beneath the Western Desert consists of a thick sequence of highly permeable sandstones with clay lenses overlying basement rocks. Extensive studies on this reservoir,(2) including mathematical modelling, show

(1)The information was derived from aeronautical navigational maps published by the U.S. Defence Mapping Agency to show human constructs in remote areas, to provide orienting landmarks for navigators (World Resources Institute 1992).

(2)The studies were conducted by The Egyptian Desert Reclamation Authority (embodied in many reports and commented upon in Ezzat, 1974), The Research Institute of Ground Water (RIGW), Ministry of Public Works and the UNDP Food and Agricultural Organisation (FAO), 1976. A summary is also to be found in the Egypt Master Water Plan Technical Report # 4 (1981) written by Khafagi, Sabri & Carr.

that it is possible to increase extractions to about one billion cubic meters a year for the next 50 years without the water level falling to more than 100 meters below ground level and without having to resort to major lateral transfers. This amount of water represents about 2 percent of the total needs of Egypt today. At present the amount of water extracted from the reservoir is about 400 million cubic meters a year: 95 million from Kharga, 195 million from Dakhla, one million from Farafra, 50 million from Bahariya and 60 million from Siwa. These can be increased to one billion cubic meters mainly by boosting the extractions from Dakhla to 400 million and from Farafra to 350 million cubic meters.

The amount of water that can be extracted from this reservoir is limited by its very nature because it is not replenishable. It is, in fact, fossil water that accumulated during the past pluvial periods which we have elaborated upon in Part I of this book. For a long time most authors believed that this water was replenished from the rains in the Tibesti area and the African Sahel. This has been proven not to be the case.

The ground water reservoir in the Eastern Desert and southern Sinai is small since the relief of these areas does not allow the water to soak into the ground but rather to run off either to the Red Sea or to the Nile. Northern Sinai, on the other hand, is flat and receives the drainage of more than two thirds of Sinai via Wadi el-Arish and its tributaries. The northern coastal areas of Egypt, and for a very short distance inland, receive between 100 to 200 millimeters of rain a year and a total amount of 1.4 billion cubic meters a year. This is used for sporadic cultivation of barley and other winter crops along the Mediterranean coast.

Recent attempts have been made to store torrential rains by damming some wadis of the coastal areas of Sinai, but such attempts have failed because the torrents are sporadic and come in sudden and heavy spates which destroy the strongest of structures. These attempts on the part of modern Egyptians were no different from those of their ancestors. The oldest known dam was built along Wadi Garawi to the southeast of Helwan (south of Cairo) during Old Kingdom times in Ancient Egypt. The dam broke down with the first torrential rainfall. The ruins of this dam, known as Sadd el-Kafara, can still be seen (Murray 1955).

The main source of water for Egypt, therefore, is the Nile which is now being regulated by the High Dam; its waters enter Egypt at Aswan in the range of 55.5 billion cubic meters a year. These are used to satisfy the agricultural, industrial and domestic needs of the country. In the 1970's, with the realization that water had become a critical resource, the Egyptian Government asked the UNDP to finance a study to be conducted by the World Bank and the Ministry of Irrigation and Water Resources to set up a Master Water Plan. The aim of the Plan was to survey the present-day consumption patterns of the water available to Egypt at present, estimate the amount of water needed in the future with special reference to the new reclamation projects that it has to undertake to cope with the needs of its growing population, and to propose ways by which Egypt can procure the needed amount of water. The task was fraught with difficulties since the basic data pertaining to the use of water in Egypt is not available and, when found, is often inconsistent. Also the aims of the Plan were changed several times before they were finally set. Three alternative plans for the future use of the waters were envisaged: the first was based on the assumption that the country's water supply would not increase beyond what is available at present while the second and third were drawn to determine the additional amounts of water that the country would need if it were to go ahead with plans to reclaim new lands. The first scenario was based on the actual supply of water available to Egypt including its share from the

Jonglei Canal which, it was hoped, would be completed in the mid 1980's. By subtracting from this quantity Egypt's present and future needs the rest would be available for land reclamation purposes. The second scenario aimed at determining the quantity of water that Egypt would need if it were to maintain a growth rate of 4.9 percent in the agricultual sector, of which 1.9 percent would come from newly reclaimed lands. The third scenario was the same as the second with a 3 percent rate of growth in the agricultural sector, of which 0.5 percent would come from newly reclaimed lands.

Perhaps the two most important achievements of the Plan were the building of a water data base and the organizing of a team of specialists who became conscious of water as a valuable and rare resource which needed to be preserved and managed efficiently. In a country which has always taken water for granted this was a great achievment. Among the pervasive beliefs in Egyptian culture is that water, like air, is God-given and free. Any pricing system and controls on its use are totally unacceptable and almost blasphemous. The perception that water is abundant is sometimes manifested in frivolous but revealing ways. A former President of Egypt offered to channel part of the water of the Nile to Jerusalem as a gesture of good will; a prominent member of Parliament once submitted a proposal to construct a pipe line from Lake Nasser to Saudi Arabia to supply it with fresh water; and some investors presented projects to divert the "excess" waters of the Nile to the desert.

The following discussion makes clear that the water available to Egypt is barely sufficient to satisfy its present needs, and that there is very little excess to be used for large-scale land reclamation programs even though these programs are vital to alleviate the population pressure on the old lands. The per capita share of agricultural land in Egypt is barely 700 square meters. This miniscule area must satisfy not only the individual's basic needs but must also contribute to the building of the necessary infrastructure essential to the individual's movement, education and health care, as well as to the building of industry and public utilities. It is no wonder that the Egyptian Government gives priority to land reclamation programs aimed at increasing the area of land upon which Egyptians can live and move. The discussion in Part III has shown that all the land reclaimed during the past three decades has barely compensated for the increase in the size of the urban areas.

2.1.1. The present use of water

It has already been mentioned that the only available water for the inhabited part of Egypt is what comes with the Nile and is released from the Aswan High Dam reservoir. There is little if any that is added to this water whether in the way of rainfall, underground seepage or any other source. The cycle is closed with only one input from the High Dam. The outputs of the cycle are the main object of study of the Master Water Plan and a large number of publications (Radi 1986–1990; Attia 1989 and others). There are five main outputs for the Nile waters that enter Egypt: (1) evaporation and transpiration losses, (2) non-recoverable domestic and industrial consumption, (3) non-consumptive use for inland navigation and hydropower generation during the yearly canal closure period, (4) evapotranspiration, and (5) drainage to the sea and the inland lakes.

Evaporation and transpiration losses along the main channel of the river and the secondary canals are estimated to be about 2 billion cubic meters a year.

2.1.1.1. Domestic consumption

Estimates differ as to the amount of water used for domestic and municipal purposes. The data are conflicting and difficult to obtain as is noted by the team of Egypt's Master Water Plan assigned to the study of this subject (Technical Report 9, 1981). Field data and the 1976 census show that 59 percent of urban households and 3 percent of rural households have tap in dwelling; 28 percent of urban households and 61 percent of rural households have tap in building but outside dwelling; 13 percent of urban households and 36 percent of rural households have no access to a tap in their dwelling or in a nearby building and lie outside the national water distribution network. Technical Report 9 of the Master Water Plan estimates that the average daily per capita consumption of water for domestic purposes in 1976 was 114 liters and that the total amount of water withdrawn from the Nile for this purpose was one and a half billion cubic meters. In 1982, estimates of the daily per capita consumption rose to 182 liters and the annual amount of water withdrawn from the river for that purpose rose to 2.2 billion cubic meters. Fifty-seven percent of that amount was consumed in Cairo alone where the daily per capita consumption reached 322 liters. This is an extremely high figure when compared with the daily per capita consumption of 300 liters of major European cities. There are no definitive figures for the consumption of water for domestic and municipal purposes in the 1990's, but projected figures give an estimate of a total amount of 3.8 billion cubic meters per year of which about 2.2 billion cubic meters are either lost or are so polluted that they cannot be reused again.

2.1.1.2. Industrial consumption

Estimates of the quantity of water used in industry also vary from one study to the other. The Master Water Plan (Technical Report 9, 1981) reports the results of a field study conducted in the late 1970's to which a fair number of industries responded. It shows that the quantity of water used in the industries of Egypt was in the range of 2 billion cubic meters per year. Of these the industries of upper Egypt used some 185 million cubic meters, those of south Cairo about 915, those of north Cairo about 450 and those of the delta region and Alexandria about 415. Since these estimates were the result of a survey to which there was only a partial response from the industries, most authors believe that the actual amount of water used in industry is probably closer to 3 billion cubic meters a year. Most of this water drains back to the Nile or, to a lesser extent, to the canals and drains. These discharges flow back into the system replete with pollutants. Data on these pollutants is woefully inadequate. They range from heavy metals, oils, grease, salts, dyes and phenol to other toxic chemicals. Although the amounts of the pollutants discharged into the river seem to be beyond the limits which the river can take without having the quality of its water adversely affected, no one seems to have determined these limits or the sink of these pollutants. The river decomposes, absorbs and sheds off some of them to other sinks. River sediments, for example, seem to be the permanent sink of heavy metals and other soluble trace metals. How much of these can go in the sediments without causing a health hazard is not known. Determining these limits is essential if the laws, which the Egyptian Government is currently promulgating to control and curb pollution, are to be applicable and credible.

2.1.1.3. Non-consumptive use for inland navigation and hydropower generation

The Nile system including the river distributaries, canals and drains is used extensively for navigation. At present, the current irrigation releases are adequate for navigation purposes during all months except when irrigation requirements are low and the canals are closed. The period of canal closures is in winter when plants are dormant, the air is moist, and the canals are

cleared and their cross sections reshaped. To maintain the water level of the Nile and its distributaries for navigation during this period about one billion cubic meters of water are released into the Nile from Aswan. At present this amount of water is not used for irrigation and is discharged into the sea.

The water requirements for hydropower generation are fully met by the irrigation releases except during the canal closure period. For many years Egypt continued to release an additional 2 billion cubic meters during this period to assure that electricity would be generated at the same level as other months of the year. None of this water was recoverable to the irrigation system and it was left to pass to the sea. Conditions during the drought years of the 1970's and 1980's made it impossible to continue this policy and the releases were greatly reduced resulting in a major reduction of power generation. The level of the Aswan High Dam reservoir fell to critical lows (section 4.3.2, Part III) not only because of the drought but also beause of the non application of the lower rule of the operation of the dam. During these years only 1.8 billion cubic meters were released during the canal closure period.

The amount of water that is lost to the system as a result of releases to satisfy the requirements of navigation and hydropower generation, therefore, is in the range of 1.8 to 3.8 billion cubic meters a year depending on the amount of water released for hydropower generation. Plans are under way to make use of this water by diverting it to the northern delta depressions and lakes for storage and re-use.

2.1.1.4. Agricultural use (evapotranspiration)

Agriculture is the largest user of water in Egypt and will remain so for a long time to come. All the water with the exception of that used for domestic purposes and industry or that which is discharged into the sea during the period of canal closure is used in agriculture. That amount is in the range of 47 to 49 billion cubic meters a year or about 84 to 88 percent of the total amount of water available to Egypt. This water is used for the irrigation of the old lands as well as the new lands that are being reclaimed. Estimates differ as to the amount of water used to irrigate the old lands and the new lands.

As has already been mentioned there is no concensus as to the exact area of the old lands of Egypt. Not only is the extent of this area constantly changing because of infringements on it resulting from population pressure and increased human activity, but also because the register of land tax does not include all the lands in view of the exemption of small land holdings (less than 5 feddans) from the tax. An actual survey of the land occupied by each crop in each of the provinces is carried out yearly by Egypt's Ministry of Agriculture. The 1988 survey showed that the total area of the cropped lands was 11.458 million feddans (representing an area of 6.1 million feddans with a cropping intensity of about 190 percent). According to this survey the area of the old lands remained constant during the past three decades inspite of the great effort given to land reclamation during these years. The new productive lands that were added as a result of such efforts barely compensated for the lands that were lost as a result of the expansion of urban areas, the building of industries, roads and other infrastructure and the destruction of the top soil.

During these decades there was a change in the areas growing various crops. From 1972 to 1988 the areas that were occupied by cotton and rice were reduced from 14 and 11 percent of the total cropped area to 9 and 7.3 percent respectively. On the other hand, the areas growing

wheat and vegetables increased from 11 and 7 percent of the total cropped area to 13 and 10 percent respectively. Clover (*Bersim*) and corn continued to occupy 15 and 20 percent of the total cropped land respectively. The nature of crop rotation and succession also underwent change. This was due to the greater maneuverability offered by the regulation of the water released from the High Dam (Hamdan 1984). It became possible, for example, to cultivate corn as a summer crop. Prior to this it was almost a *nili* crop.

The following table shows the change in the areas of the main crops of Egypt between 1972 and 1988. The area occupied by these crops diminished from 78 percent of the total cropped area in 1972 to 65 percent in 1988 as a result of the increase in the cultivation of non-traditional crops.

Table V: Areas of main crops (in 10^3 feddans)

	1972	1988
Corn & Sorghum	2691	2798
Bersim catch crop	1254	955
Bersim permanent	1565	1614
Cotton	1552	1014
Rice	1146	838
Sugar cane	202	267
Total	8410	7486
Total cropped land	10,838	11,460

Estimates of the amount of water used in irrigating the cropped lands of Egypt differ greatly, and there are several estimates for the water requirements of crops cultivated in a unit area of land. The lowest estimates come from a field study by the Ministry of Irrigation (Kinawy 1976). They were based on the measurement of the amount of water actually reaching the areas occupied by each crop in every province. According to this study the average amount of water needed for one cropped feddan is 3280 cubic meters per year. The highest figures come from the documents of the five-year plan (1987/1988–1991/1992) in which the average requirement of one feddan is estimated to be 4480 cubic meters (Abu Mandur 1988). In estimating the irrigation requirements of the old lands, the Master Water Plan used a round figure of 4000 cubic meters as the requirement of one feddan of these lands. The Main Report of the Plan (1981) puts the amount of water needed for the old lands at 45.8 billion cubic meters.

In modern literature the water needed to grow a certain crop (water duty) is usually equivalent to the depth of water to be applied to the land. In Egypt it varies, according to whichever estimate is accepted, from 0.78 to 1.06 meters. These figures are comparable to, if not lower than, those in other areas where more sophisticated methods of agriculture are practiced. In northern Israel the figure is 0.89 meters (Malouf 1991).

The water requirements of the different crops shown in Table V are among the highest in water consumption (Kinawy 1976). One feddan of sugar cane requires 17,800 cubic meters a year, rice 8870 cubic meters, cotton 3620 cubic meters, corn (and sorghum) 3420 cubic meters and Bersim 3260 cubic meters. In 1988 these five crops consumed about 32.5 billion cubic meters. Fruit trees are among the highest in water consumption; and land growing them used

about 4.2 billion cubic meters. The remainder of the crops (which occupied about 19 percent of the cropped area) used about 8.5 billion cubic meters.

It is also difficult to estimate the amount of water used in the new lands. The area of the lands reclaimed from 1979 to 1989 was 747,000 feddans, according to an internal report of the World Bank (1990). The amount of water needed for one feddan of the lands reclaimed in the 1960's was over 10,000 cubic meters; the soil of most of the lands was sandy and the irrigation was affected by flooding. In the 1987/1988–1991/1992 plan of development the amount of water estimated for the reclamation of one feddan was reduced to 8510 cubic meters (Abu Mandur 1988). Many of the new lands are adopting modern methods such as drip irrigation. It is possible, therefore, to accept the lower figure given in the last five year plan.

The field irrigation efficiency or the amount of water used by the plant and released as evapotranspiration is estimated to be in the range of two thirds of the water used in irrigation. With the current cropping pattern in Egypt this consumptive use amounts to about 35 billion cubic meters a year. The other third of the water sinks into the ground or flows to the drains and from there to the sea or the terminal lakes. In upper Egypt all drains flow back into the Nile except those in the Fayum which pass to the interior depressions of Birket Qarun or Wadi Rayan. Some of this water is recuperated and reused for irrigation. At present about 2.5 billion cubic meters of water are pumped from the ground water reservoir and about 3.5 billion cubic meters are lifted from the drains to the irrigation channels. The drainage water is mixed with fresh water before reusing. In 1988 discharges of pumping stations lifting drainage water to irrigation channels were as follows (in billions of cubic meters): 1.4 from the eastern delta region, 0.4 from the middle delta region, 0.8 from the west delta region and 0.9 from the Fayum. This amount of reuse makes the overall irrigation efficiency (the ratio of the difference between canal irrigation water and net drainage water to the canal irrigation water) about 79 percent.

The irrigation water balance is as follows:

	Input (10^9) m^3	Output (10^9) m^3
Going to the old lands	45.5	
Going to the new lands	6.5	
Evapotranspiration requirements		35
Field drainage & seepage		17

and the balance of the field drainage and seepage is as follows:

	Input (10^9) m^3	Output (10^9) m^3
Field drainage & seepage	17	
Pumped groundwater		2.5
Reused drainage water		3.5
Net drainage to the sea		11

The present balance of the water going into Egypt is as follows:

	Input (10^9) m^3	Output (10^9) m^3
Released from Aswan	55.5	
Evapotranspiration		35
Net drainage to the sea		11
Domestic & Industrial non consumptive use		2.2
Navigation & hydropower requirements		1.8–3.8
Evaporation losses		2
Surplus for use in reclaiming new lands		1.5–3.5

2.1.2. The future use of water

There is no indication that there will be an increase in the amount of water available to Egypt from the Aswan High Dam in the forseeable future. It is possible that this amount will be increased by 2 billion cubic meters when the Jonglei Canal is operating. The work on the canal has been interrupted since 1983 because of the civil war which is raging in southern Sudan. Until this conflict is settled Egypt will have to cross out that amount from its water itinerary. The chances of increasing Egypt's water supply through the building of irrigation projects in the upstream states, as has been advocated since the beginning of the twentieth century, is minimal indeed. Not only is it difficult to work out agreements with these states, almost all of which are in turmoil, but there are no viable projects that are acceptable to all of them. In addition to their environmental and social impacts, all projects floating at present are extremely expensive and do not seem to be viable with regard to the delivery of their stored or diverted water to the downstream states along the present-day channels.

Therefore, and for a long time to come, Egypt will have to live with its present-day supply of water and will have to adjust its water and foreign policy to this fact. As a downstream basin state it is in a vulnerable position. Unfortunately all precedents show that International Law is no guarantor of the rights of basin states in international rivers. The great projects on the Euphrates River which Turkey, as an upstream state, has built without consulting with the downstream states resulted in the reduction of the flow of the river in both Syria and Iraq, by 40 percent and 80 percent respectively.

Egypt's share of the Nile water is coveted not only by the upstream Nile states but also by many of its water-starved neighbors. Proposals are being put forward which would allow Israel to get a share of this water (Ben Shahar et al. 1989, Malouf 1991) under the pretext that Egypt does not use its water efficiently and has water to spare. For Egyptians, however, the savings that may come from a more efficient use of the water will barely satisfy the future needs of the burgeoning population of the country. We have already seen that there will be barely any surplus water for the reclamation of new lands so vital to an over-crowded country. The new lands which are open for reclamation have low quality soil. They lie on higher ground and require lifting up of water. Most donor nations and international organizations consider land reclamation to be not

viable and discourage Egypt from using its funds on such projects. Egyptians, however, insist that land reclamation is the only way open to alleviate population pressure and they recommend going ahead with it irrespective of the cost. They quote the case of the Tahrir province (west delta) which was reclaimed in the 1960's and was considered to be not viable by many critics for similar reasons. Today the province is one of the most productive lands of Egypt. The overriding need to alleviate population pressure has to be considered as a factor in the economic viability of these projects.

In addition to the water needed for reclaiming new lands, Egypt's growing population will need more water in the future. Faced with the prospect of increasing demand and a fixed supply, Egypt has no alternative but to use its water more efficiently. There is no doubt that there is a great deal that can be done to change the wasteful patterns of water use current in Egypt today. The first and most obvious is for Egypt to store the water that is released during the canal closure period (which we have estimated to be between 1.8 to 3.8 billion cubic meters a year) and which at present flows to the sea. Plans have already been drawn to store this water in the depressions of the northern delta.

The second is to increase the amount of water pumped from the groundwater reservoir under the delta from the current 2.5 billion cubic meters to 7 billion cubic meters a year. Recent studies have shown that an increase in groundwater pumping can take place without causing major intrusion of salt water from the Mediterranean Sea into the reservoir. This increase in pumping can take place only when strict regulatory rules are enforced with regard to the spacing of the wells and the amount of water that can be pumped from them. Not only will this water add to the supply available to Egypt but it will also have the added advantage of lowering the water table and contributing to the solution of the problems of drainage (El-Gabaly 1988). If this water is not pumped it will accumulate, raise the water table level and ultimately find its way to the sea.

The third is to increase the use of the drainage water. There are at present plans to increase the amount of water pumped from the drains from the current 3.5 billion cubic meters to 6.5 billion cubic meters. It is essential that the drains do not receive municipal sewage as is currently occurring. A further increase of one billion cubic meters in the water available to Egypt can be obtained by treatment of the sewage. The net result of all these measures is an increase in the water supply of between 10–12 billion cubic meters a year.

Egypt has a long way to go in the field of efficient water use in agriculture to benefit from the margin of maneuverability that the building of the High Dam has afforded it. On the whole, Egypt still has only two major crops, as it used to have prior to the building of the dam, and the cropping intensity is still in the range of 190 percent. The regulation of water releases by the High dam should make it possible to cultivate three crops on all the lands so that an additional crop would occupy the land between the middle of September and the beginning of March, making use of the water released during the canal closure period and increasing the crop land of Egypt to 18 million feddans and the cropping intensity to close to 300 percent. Egypt can also save water by cultivating crops that need less water to grow. An example would be to replace the water-intensive sugar cane crop with beets. Furthermore, Egypt's agricultural research should be directed toward deriving new breeds that would mature early and remain in the land for shorter periods of time.

Egypt also has a long way to go in the field of water management. The canals need to be redesigned so that they can carry a smaller quantity of water to their terminals. An efficient schedule for water rotation needs to be devised. This is possible only when crops of the same water requirements are grouped at one water outlet. The liberalization of agricultural policy should be limited to the repeal of price controls and should not meddle with crop mixes and groupings.

2.2. The Sudan and the Future Use of the Waters of the Nile

The Sudan is the largest of all the basin states, extending across 20° of latitude (from latitude 3° to latitude 23° north of the equator) and more than 15° of longitude. It has an area of about 2.4 million square kilometers (or 574 million feddans) stretching across several climatic, soil and vegetational belts (Fig. 4.1). The northern third of the country is desert while its remaining two thirds receives rains of different intensities. The rainfall ranges from 75 to 300 millimeters a year in areas lying between latitudes 15 and 17°, from 300 to 800 millimeters a year in areas

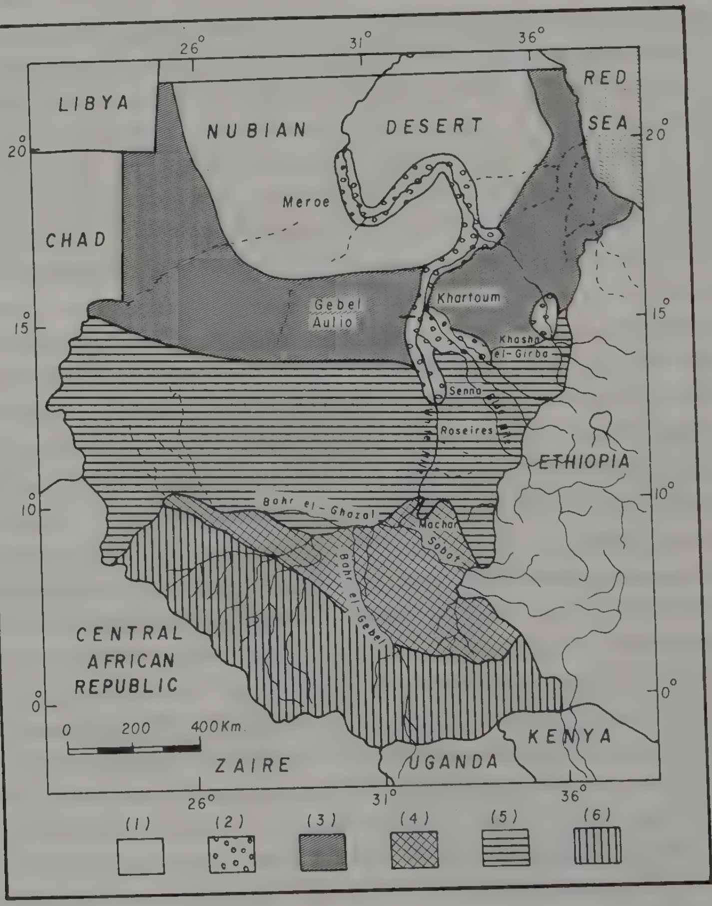

Fig. 4.1. Land use in the Sudan (after Radi 1987, with modifications). 1. desert, 2. irrigated agriculture, 3. nomadic herding, 4. pasturing, 5. dry farming, 6. primitive agriculture.

between latitudes 9 and 15° and from 800 to 1500 millimeters in areas to the south of latitude 9° north. Lands receiving more than 400 millimeters of rain a year in areas lying to the north of latitude 9° are suitable for dry agriculture. Their area is in the range of 235 million feddans or close to 41 percent of the surface area of the Sudan. Lands which receive less than 400 millimeters of rains a year are suitable for herding, mainly sheep and camel. The lands suitable for dry agriculture lie in the Sahel zone which is highly erratic in its rainfall and is subject to frequent droughts. Its natural vegetation ranges from typical savanna in the south to shrub and grass deserts in the north. The area to the south of latitude 9° is of equatorial nature although its eastern part (which extends into Kenya) receives lesser rains and has a desert-like savanna vegetation. A large part of this area is covered with the papyrus swamps of the Sudd region which are used as pasture lands for cattle raising. Another part of this area is covered with tall grass savanna.

Sixty percent of the population of the Sudan lives in the northern semi-arid part of the country. From this population comes the class which has traditionally ruled the Sudan with its vast regions and varied ethnic groups. The primary goal of this elite class is the development of the region where they live, hence the great emphasis given in the national development plan to irrigated agriculture and the development of the banks of the Nile in the northern semi-arid regions. The other regions, which have great water potential, receive little attention. In addition to the rains which fall on these regions, there are a variety of water resources ranging from rivers other than the Nile to a vast renewable groundwater reservoir. Among the rivers, mention is made of the Gash (with a discharge of 800 million cubic meters a year), the Barka (with a discharge of 700 million cubic meters a year) and the rivers emanating from Gebel Marra in the west (with a total discharge of 300 million cubic meters a year). The amount of rainfall which falls on the areas suitable for dry agriculture is estimated to average about 140 billion cubic meters a year. This, when complimented with what can be extracted from the groundwater reservoir, would cultivate an estimated 6.5 million hectars assuming that one third of the rainfall would be recovered and that each hectar would need about 7500 cubic meters of water (Radi 1987).

Most of the development plans of the Sudan, however, are concentrated on the development of irrigated agriculture along the banks of the Nile. In section 4.2, Part III, we discussed the history of the introduction and development of irrigated agriculture in the Sudan. There are at present about 4.4 million feddans under cultivation almost half of which lie in the Gezira and Mangil areas between the Blue and White Niles (Fig. 3.26). These, together with the lands around the Khashm el-Girba area, Atbara, are the only lands that are irrigated by gravity from water stored in dams erected along the Blue Nile and the Atbara. All other lands are irrigated by pumps. At present, the Sudan uses only about 14.5 billion cubic meters a year, some 4 billion cubic meters short of its share of 18.5 billion cubic meters according to the 1959 Water Agreement. It plans to use this water as well as the water that will accrue to it from the Jonglei Canal (about 2.3 billion cubic meters) to irrigate an additional 1.7 million feddans along the banks of the Blue Nile (500,000 feddans), upper Atbara (620,000 feddans), the White Nile (210,000 feddans), the Main Nile (200,000 feddans) and around Bahr el-Gebel in the southern part of the country (200,000 feddans).

These plans require an increase in the water storage capacity on the Nile. At present the storage capacity is estimated at about 8.1 billion cubic meters affected at the following dams: Sennar (0.6 billion), Roseiris (2.7 billion), Khashm el-Girba (1.3 billion) and Gebel Aulia

(3.5 billion). The Sudan has a plan that calls for the heightening of the Roseiris dam to increase its capacity to 6.5 billion cubic meters (an increase of 3.8 billion cubic meters from its present-day capacity), the building of a dam at the Setite River (upper Atbara) with a capacity of 1.6 billion cubic meters and the construction of another dam on the Main Nile in Nubia at Merowe with a capacity of 1.6 billion cubic meters to be increased to 7 billion cubic meters at a later stage. These dams (especially along the Blue Nile and Atbara) will face the problem of silting which is currently reducing the storage capacities of existing dams. The Sennar loses about 40 million cubic meters of its capacity every year and the Roseiris had already lost three quarters of its dead storage capacity 10 years after it was built in 1966. The heightening of the latter dam will temporarily solve this problem but the problem will reappear again more acutely after the year 2010 (Blue Nile Consultants 1978). Dams in the Sudan also face the problem of high rates of evaporation which reduce the amount stored to almost one half, as is the case with the Sennar and Gebel el-Aulia dams. Many authorities are recommending the building of the Merowe dam in Nubia to avoid the high rates of silting expected at the Blue Nile and Atbara and to make use of the high slope of the river for hydropower generation.

The Sudan has long-range projects to increase the irrigated areas around the banks of the Nile by another 3.4 million feddans: along the Blue Nile and its tributaries (1.6 million feddans), around the Main Nile in the northern provinces (1.5 million feddans) and in Bahr el-Gebel (300,000 fedans). This increase will require an extra 16 billion cubic meters of water over and above its present-day share. It is difficult to imagine how this could be realized even if all the upper Nile projects proposed in Egypt's century storage scheme (which were conceived to provide 16 billion cubic meters a year to be equally divided between Egypt and the Sudan) were to materialize. In fact, it is difficult to imagine how any of these projects could materialize in the near future. Not only have they not been fully studied as to their feasibilty and their social, economic and environmental effects, but they will also be difficult to negotiate since they will be viewed by the inhabitants of south Sudan and the upper Nile states as schemes designed to draw waters from the southern parts of the Nile for the benefit of the north. Until such problems are addressed we can safely neglect from our assessments the long-range plans of the Sudan for developing its irrigated agriculture.

2.3. Ethiopia, Africa's Water Tower

Ethiopia is a mountainous country which is divided by the low-lying rift into a western highland and an eastern plateau. The western highland, whose water drains toward the Nile, is bound by the steep wall of the rift on its east side and includes the high and snow-covered peaks of Ethiopia the highest of which, Ras Dahan of the Simien mountains (northeast of Lake Tana), rises to an elevation of 4620 meters above sea level. In contrast, there are the low lands of the Ethiopian Rift whose lowest point in the Danakil depression is 112 meters below sea level. The eastern plateau slopes gently toward the Indian Ocean to where most of the drainage is directed. The Ethiopian Highlands are truly rugged; they are difficult to cross or conquer and have helped Ethiopia keep its independence for most of its history, although it was encircled from all sides by hostile forces. In the nineteenth century Egyptian forces penetrated Eritrea, then advanced southward along the coastal plain to the ports of Musawa and Zela and from there into Harrar Province in the eastern plateau.

Ethiopia is the richest Nile Basin state in its water resources. Its highlands are the source of the rivers which flow into Somalia and the three major tributaries which flow into the Nile.

Although the area of the drainage basin of these three tributaries (the Blue Nile, the Atbara and the Sobat) is about one eighth of the entire basin of the Nile, it provides the river with about 84 percent of the water which reaches Aswan. The average amount of water contributed by a unit area of 1000 square kilometers of the basin of these three tributaries is high when compared with that contributed by the same unit area of the whole basin of the Nile. The average contribution of a unit area of the basin of the Blue Nile is about 8 cubic meters per second while that of the same area of the Atbara and Sobat basins is about 4.5 and 4 cubic meters per second respectively. The average contribution of the same area of the Nile Basin as a whole is only about 0.86 cubic meters per second.

In addition to these three tributaries of the Nile there are the Gash and the Barka rivers which emanate from the Ethiopian Highlands but fail to reach the Nile and whose waters are dissipated in the plains of the Sudan. Other interiorly drained rivers occupy the Ethiopian Rift and terminate in the interior lakes of that rift. Of these the Omo (which flows in Lake Turkana) and the Awash (which flows in Lake Abbe) are the most important. Several small ephemeral rivers emanating from the Ethiopian Highlands flow toward the Red Sea while several major rivers flow toward the Indian Ocean of which the Guba and the Webi Shebelle are the most important. The discharge of the rivers flowing from the Ethiopian Highlands is about 180 billion cubic meters a year of which about 70 billion cubic meters go to the Nile and 20 billion cubic meters to the Indian Ocean.

The principal rainy season is in the summer between the beginning of June and the end of September reaching its peak in the month of August. The amount of rainfall differs from one place to another. It is small and is in the range of 200 to 500 millimeters per year in the north in the Eritrean plateau and along the Red Sea coast, and is large and is over 1500 millimeters a year in the south in the vicinity of the Sobat sources. The average rainfall over the entire Ethiopian Highlands is about 1200 millimeters per year contributing a total amount of close to 480 billion cubic meters. More than half of this amount runs to the Red Sea or the Indian Ocean and the rest is carried by the rivers or seeps into the ground to form the groundwater reservoir which is replenished at an estimated rate of about 20 billion cubic meters a year. The effect of the varying rates of rainfall on the different provinces of Ethiopia can be seen in Fig. 4.2 where the size of each of the tributaries of the Blue Nile reflects the amount of water carried by the basins of these tributaries. In this figure it is clear that the Didessa and Dabus tributaries which come from the southeast contribute the most water.

Ethiopia is virtually virgin land with regard to the development of its natural resources. Water is abundant. The amount that is available to Ethiopia and is carried by its interior rivers or its groundwater reservoirs is in the range of 110 billion cubic meters a year. The larger part of this water is carried by the rivers which run in the Ethiopian Rift where the weather is harsh and where few people live. Most people live in the Highlands on lands whose elevations range from 1800 to 2400 meters above sea level and where the temperature remains almost constant, fluctuating around 20° celsius throughout the year. During the 1970's and 1980's, when Ethiopia was subjected to long periods of drought, there were attempts by the Ethiopian Government to relocate people to the areas around the rivers of the Ethiopian Rift, but these attempts were fiercely resisted. They aroused great suspicion especially since they took place during the protracted civil war that was raging in that country at that time.

Ethiopia is one of the few African countries whose rivers have been well studied and whose basins have been mapped in detail (U.S. Bureau of Reclamation 1964). The studies were made

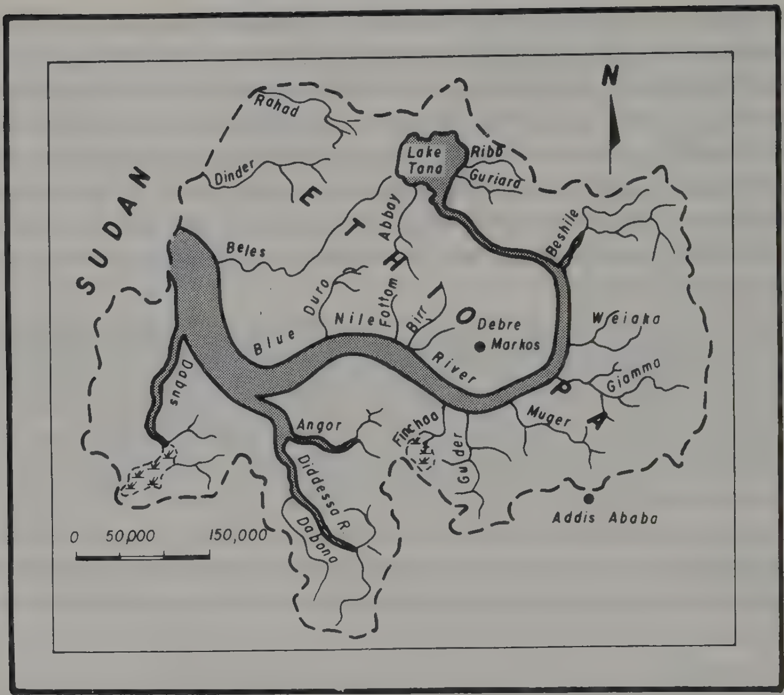

Fig. 4.2. Blue Nile runoff distribution (runoff rate is proportional to the width of the rivers), after U.S. Bureau of Reclamation Report (1964).

by the United States Government between 1959 and 1964 in response to an invitation proffered by the Ethiopian Government after Egypt's decision to build the High Dam. It is possible that the United States accepted to carry out the study so that it could send a message to Egypt which at that time was embarking on an independent policy that did not please the United States. The nightmare that has haunted the Egyptians throughout their history has been the fear that the Blue Nile waters would be blocked and prevented from coming to Egypt. Up to the time of that study little was known about the river which was navigated between 1926 and 1929 by Major Cheesman, the English Consul (U.S. Bureau of Reclamation 1964). There was, however, a general belief among the Egyptians that the Blue Nile ran in a deep canyon and that it would be difficult to divert or to block its waters. Any dam on it would have to be high, small in capacity and subject to quick siltation.

The scope of the Bureau of Reclamation study included the entire Blue Nile Basin in Ethiopia, its hydrology, water quality, geology, physiography, mineral resources, land use, ground water and potential economic development. It involved the establishment of stream flow measurements throughout the basin (59 gauging stations) as well as extensive aerial surveys and mapping. The Bureau's study shows that there are no lands along the Blue Nile which can be irrigated; the proposed irrigation projects are located in the plateau valleys at elevations of between 335 and 920 meters above sea level. They lie mainly around Lake Tana, on the Fincha and the Angar tributaries and on the Ethiopian–Sudanese border (Fig. 4.3). The total area of these lands is slightly less than one million feddans. Their total annual

water requirement is estimated to be about 6 billion cubic meters. The irrigation and hydro-electric projects proposed by the Bureau's investment program are summarized in Table VI.

The emphasis of the Bureau's report is on the potential of the Blue Nile as a source for the generation of power. The major hydroelectric projects proposed lie along the Blue Nile (for locations see Fig. 4.3). They benefit from the fact that the river falls about 1300 meters along its 900-kilometer journey from Lake Tana to the Ethiopian–Sudanese border. Of these it falls about 500 meters in the first 100 kilometers of its course. Four dams, the Karadobi, Mabil, Mendaia and Border, are supposed to intercept the entire flow of the river; their combined initial active storage capacity would be about 50 billion cubic meters which is equal to the mean annual flow of the river. Together the four dams would have an annual electricity generation of more than 25 billion kilowatt hour, about three times the annual production of the Aswan High Dam. Other hydroelectric projects included in the Bureau's plan would add an additional 5 to 10 billion kilowatt hour per year.

Because of the high cost of executing all the proposed projects the Bureau recommended that Ethiopia start with some of the smaller projects and aim to finish the following projects by the end of the twentieth century: the Fincha, Dabana, upper Beles, Dabus, lower Diddessa, lower Guder, Angar and Gilgel Abbay. The four large dams on the Blue Nile were to be postponed to the twenty-first century. The twentieth century projects were estimated to cost (in 1964 prices) about 2 billion Ethiopian dollars. Today the execution of these projects would probably cost between 50 and 100 times that amount.

There is no doubt that the report was extremely optimistic in its evaluation of the will and potential of Ethiopia to build all these dams. We are now close to the end of the twentieth century, and of all the projects that were supposed to have been built by then only the Fincha project has been completed. The project for this dam was studied by the World Bank in 1969 and the dam was built in 1972 with an initial storage capacity of 400 million cubic meters per year. The European Community is looking into the possibility of diverting the waters of the Amarti tributary to make use of the dam in generating power (Whittington & Haynes 1985). At present, considerably smaller versions of the Bureau's upper Beles and middle Beles projects are being constructed with the help of the Italian Government. Both will have an initial storage capacity of 100 million cubic meters only. In addition to the American study, the European Community is looking into the feasibility of building a dam at Gambeila on the Sobat River with an ultimate storage capacity of 1.5 billion cubic meters that would be used to cultivate some 750,000 feddans. At present, only a pilot project of 35,000 feddans has been completed on that site.

If and when all the projects proposed are executed Ethiopia will be able to withdraw about 6 billion cubic meters of water from the Blue Nile, half a billion cubic meters from the Atbara and one and a half billion cubic meters from the Sobat. If these projects are built without consultation with the downstream riparians their effects would be the disruption of the downstream states' economies and the destabilization of their governments. However, this need not be the case; for if these projects are built cooperatively with these states, it is possible that they would be beneficial to all. Guariso & Whittington (1987) have shown that if the operation of the proposed dams on the Blue Nile is coordinated with that of the Roseiris in downstream Sudan they would have the effect of regulating the flow of the Blue Nile. Today the river discharge fluctuates greatly. During the months from January to June the monthly discharge

Table VI: U.S. Bureau of Reclamation proposed irrigation and power projects on the Blue Nile

	Project	Purpose	River	Initial capacity (10^6 m^3)	Irrigated area (10^3 feddans)	Annual Water Requirement (10^6 m^3)	Installed kilowatts (10^6 kW/ hour)
1	Megech (gravity)	Irrigation	Megech	225.3	16.6	93	—
2	Ribb	Irrigation	Ribb	312.6	36.6	194	—
3	Gumara	Irrigation	Gumara	236.7	31.0	163	—
4	West Megech (pump)	Irrigation	L. Tana	12,987.0	17.0		—
5	East Megech (pump)	Irrigation	L. Tana	12,987.0	14.1	101	—
6	NE Tana (pump)	Irrigation	L. Tana	12,987.0	12.0		—
7	upper Beles	Multipurpose	L. Tana	12,987.0	151.7	994	900
8	mid. Beles	Power	Beles	3974.0	—	—	750
9	upper Birr	Irrigation	Birr	537.4	58.4	299	—
10	Debohila	Irrigation	Debohila	50.1	10.0	56	—
11	lower Birr	Irrigation	Birr	Run of river	15.8	88	—
12	Giamma	Power	Giamma	3169.0	—	—	270
13	Muger	Power	Muger	300.7	—	—	120
14	upper Guder	Irrigation	Bello	70.6	12.2	51	—
15	lower Guder	Power	Guder	2557.0	—	—	225
16	Fincha	Multipurpose	Fincha	464.0	36.0	210	360
17	Amarti-Neshe	Multipurpose	Amarti & Neshe	847.6	20.4	116	360
18	Arjo-Diddessa	Multipurpose	Diddessa	2130.0	40.3	183	135
19	Dabana	Multipurpose	Dabana	1617.0	14.6	86	380
20	Angar	Multipurpose	Angar	3572.0	72.5	416	835
21	lower Diddessa	Power	Diddessa	4862.0	—	—	1440
22	Dabus	Irrigation	Dabus	Run of river	36.0	205	—
23	Dabus	Power	Dabus	Run of river	—	—	35
24	Dinder	Multipurpose	Dinder	3690.0	140.0	1145	180
25	Galegu	Irrigation	Galegu	798.8	27.8	228	—
26	Rahad	Irrigation	Rahad	1902.0	127.4	1043	—
27	Karadobi	Power	Blue Nile	32,500.0	—	—	6070
28	Mabil	Power	Blue Nile	13,600.0	—	—	5400
29	Mendaia	Power	Blue Nile	15,930.0	—	—	7290
30	Border	Power	Blue Nile	11,074.0	—	—	6300
31	Jiga Spring	Irrigation	Turkar Spring	—	224.0	3	
32	Gilgel Abbay	Multipurpose	Jema, Koga, Abbay	1017.0	150.0	693	285
	Total			175,385.8	1258.4	6376	31,335

Fig. 4.3. Main projects proposed for the Blue Nile in Ethiopia, after U.S. Bureau of Reclamation Report (1964).

averages about one billion cubic meters. It increases suddenly in the latter part of June until it reaches a peak of 16 billion cubic meters during the month of August. It then falls back until it reaches 2 billion cubic meters during December. Close to 85 percent of the water, therefore, comes during the four months from July to October. The effect of the building of the proposed reservoirs would be to regulate the flow of the river. Because the reservoirs would be operated to maximize hydropower generation, management policy during a normal year would need to store as much of the late summer and early fall flood waters as possible for release the following winter and spring. If Ethiopia withdraws 6 billion cubic meters a year, the remainder of the water would be released in the magnitude of 3.6 billion cubic meters each month (after taking into account evaporation losses in the Ethiopian reservoirs which are estimated to be in the range of 3 percent). The regular flow of the water would effectively eliminate the annual Nile flood and would make the High Dam reservoir more efficient since it would reduce its surface area and thus its evaporation losses. These benefits, however, cannot ensue unless the management of the Roseiris dam and the Aswan High Dam is coordinated with that of the proposed Ethiopian reservoirs.

2.4. The Lacustrine States

The lacustrine states lie in the Equatorial Lake Plateau and have all or part of their territories in the Nile Basin. Close to 20 percent of the total surface area of the Equatorial Lake Plateau is covered by the numerous lakes which stud the plateau, and close to 5 percent of the area is swamp and marsh lands. Of all the lakes of the plateau, lakes Victoria, Kioga and Albert are of

especial importance because they represent the best sites for the over-year storage schemes. The hydrology of these lakes was the subject of a study by the World Meteorological Organisation (Hydromet 1977).

Lake Victoria, which lies in the heart of the plateau, is an international lake. 43 percent of its area lies in Uganda in the north, 51 percent in Tanzania in the south and 6 percent in Kenya in the east. The area of the basin of the lake is about 194,000 square kilometers, of which 44 percent lies in Tanzania, 23 percent in Kenya, 16 percent in Uganda and 17 percent in Rwanda and Burundi. The rivers which drain these areas contribute 46, 12, 30 and 12 percent of the total water flowing into the lake respectively. The rainfall averages about 1700 millimeters a year, and the evaporation rate is very high amounting to about 1470 millimeters per year. That is why the amount that the rainfall adds to the water budget of the lake is little inspite of the fact that it is large. The total amount of rainfall is in the range of 113 billion cubic meters of which only 14.7 billion cubic meters remain in the lake. Close to half the amount of water contributed by rainfall and river flows comes from Tanzania, 35 percent from Uganda and 9 percent from Kenya.

Lake Kioga lies in its entirety in Uganda. Its surface area is about 2623 square kilometers while the area of its basin is close to 74,713 square kilometers. Evaporation rates exceed those of rainfall causing a loss of about 1.4 billion cubic meters every year from the surface of the lake. The average yearly rainfall and evaporation is in the range of 1120 and 1516 millimeters per year respectively. The amount of water reaching the lake by the different tributaries is about 2.9 billion cubic meters per year.

The surface area of Lake Albert is about 6118 square kilometers 58 percent of which lies in Uganda and the remainder in Zaire. Evaporation exceeds rainfall and the amount of loss that the surface area of the lake suffers is in the range of 4.5 billion cubic meters. The rainfall and evaporation rates average 720 and 1500 millimeters respectively. This loss is partially compensated for by the rivers which flow into the lake.

Table VII, on the following page, summarizes the water budgets of the three equatorial lakes.

Inspite of the relatively high rainfall of the Equatorial Plateau some of the lacustrine states suffered from the droughts of the 1970's and the 1980's which touched the semi-arid western parts of Kenya where rainfall fell below the already low average for Kenya (about 518 millimeters a year). The total amount of water currently used by Kenya in its rain-fed agriculture is in the range of 14.8 billion cubic meters a year. This small amount will certainly not meet the rising demands of the fast-growing population of Kenya. Kenya has plans, therefore, to introduce irrigated agriculture and to use water from Lake Victoria and the seven rivers flowing into it from its territories. In 1979 the Kenyan Parliament created the Lake Basin Development Authority to oversee the irrigation projects in the basins of contributing rivers and along Lake Victoria (Okidi 1990, 1991). The Authority has plans to irrigate 375,000 feddans of land along the shores of the lake and another 480,000 feddans in the river basins. The amount of water that would be required has yet to be determined. A study has also examined the feasibility of inter-basin transfer from the Nzoia River to the Kerio Valley. The aim is to facilitate the irrigation of the semi-desert area of Kenya. The implementation of the projects along Lake Victoria will need the stabilization of the lake's level which, as we have already noted, has fluctuated greatly since its sudden rise in the early 1960's. Several small irrigation projects totalling about 40,000 feddans have already been implemented by the Authority or the National Irrigation Board.

Table VII

	Area (km^2)		Discharge Rivers (10^9 m^3)	Rainfall–Evaporation=Net (10^9 m^3)	Total (10^9 m^3)
	Lake	Basin			
			LAKE VICTORIA*		
Uganda	29,980	32,100	5.5	49.1 - 42.8 = 6.3	11.8
Tanzania	36,380	84,200	8.5	58.3 - 50.8 = 7.5	16.0
Kenya	3900	44,000	2.3	6.2 - 5.3 = 0.9	3.2
Rwanda & Burundi	—	33,600	2.2	—	1.2
Total	70,100*	193,900	18.5	14.7 (Net)	33.2
			LAKE KIOGA		
Uganda	2623	74,713	2.9	5.5 - 6.9 = -1.4	1.5
			LAKE ALBERT		
Uganda	3570	13,662	1.7	2.2 - 4.8 = -2.6	-0.9
Zaire	2548	2849	5.6	1.6 - 3.5 = -1.9	3.7
Total	6118	16,511	7.3	-4.5 (Net)	2.8

*Surface area of Lake Victoria in 1964 after the rise of its level and the increase of its area by about 3000 square kilometers.

These projects could well affect the downstream flow of the Nile, but the Kenyan Government recognizes no restraints with regard to the use of the water that it can lay its hands on.

Tanzania also has plans to introduce irrigated agriculture by using the waters of Lake Victoria in a manner that could well affect the regimen of the river and its downstream flow. One project is to draw water from Lake Victoria to the Vembere Plateau in central Tanzania for the irrigation of about 550,000 feddans. The scheme was originally proposed before World War I by German settlers of the then colonial power in that country. The land was to be used for growing cotton. The scheme was revived in 1969 and is still talked about, but nothing so far has been done about it.

The riparian states of the Kagera River, the main tributary of Lake Victoria, namely Rwanda, Burundi, Uganda and Tanzania, established the Kagera Basin Organization in 1977. This organization studied the possibilities of irrigation in the basin of the river and concluded that large scale projects would be unsuitable. Only three small areas covering about 6000 hectars were selected for irrigation in Rwanda, Burundi and Tanzania. Apart from the Rusumo hydropower plant, an 80 megawatt installation built in 1981, development has been impeded by lack of funds and political disputes between Rwanda and Uganda and between Rwanda, Burundi and Zaire.

3

CONCLUDING REMARKS

Most of the water that comes to Egypt at present comes from the Ethiopian Highlands and the Equatorial Lake plateau which together constitute about 20 percent of the basin of the Nile. The remainder of the basin of the Nile lies in arid or semi-arid regions where the water supply is minimal and where evaporation and seepage losses are very large. As a result, the river carries small amounts of water inspite of its great length and the large area of its basin; its waters are distributed unequitably among the basin states. This was not the case in the past. When the modern Nile made its debut some 10,000 years ago there were more rains feeding its basin especially from the arid or semi-arid parts of it. These rains increased the flow of the river and made it perennial in regimen. When these rains stopped some 5000 years ago large parts of the basin became arid and the flow of the Nile tended to decline steadily. Within that general trend and throughout its history the flow has also fluctuated greatly. Periods of drought, which periodically ravage the Sahel region of Africa, reduce the flows of the river to amounts that make the continued flow of the river to the Mediterranean improbable were it not for the ingenuity of the Egyptian engineer and the team effort of the Egyptian farmer in old as well as in modern times. Egypt, which depends on the Nile waters for its survival, had to learn from the earliest of times how to cope with periods of low flow by mastering the art of water storage and by continuously clearing the path of the river from its own silt to prevent the river's water from disappearing in its own sediments.

The distribution of the rains in the Nile Basin makes most of the upstream states rich in water resources. Estimates of the amount of water available to the different Nile Basin States differ from one authority to another. I have attempted to match the figures given in the World Bank's World Development Report 1992 (table 33, p.202), the World Resources Institute 1992–1993 (table 22.1) and Radi (1990) and have come out with the figures listed in Table VIII which, in the opinion of the author, are the most credible estimates that can be obtained from the data at hand. The table gives the amount of water available to the main Nile Basin states from the Nile and other rivers as well as from rainfall and groundwater. The rainfall figures have been adjusted to take into consideration the runoff and the extremely high rates of evaporation; they are less than a quarter of those given by Radi. The 200 million people living in the Nile Basin states have water resources that are in excess of 470 billion cubic meters per year of which 35 percent is from rains, 46 percent from rivers and 19 percent from groundwater reservoirs. Table VIII clearly shows that the degree of dependency on the Nile waters varies greatly from one state to the other. In Egypt the river provides close to 90 percent of the available water while in Kenya it furnishes only some 16 percent and in the Sudan about 46 percent. The table also includes an index to show the level of water competition. This index gives the number of people who are

Table VIII: Available water and the water competition level in some Nile Basin states

	Population (10^6) 1990	Available Water (10^9 m^3)				Water competition level (# of people competing for 10^6 m^3)
		Rain	Rivers*	Groundwater	Total	
Egypt	52.4	1.4	55.5	0.5	57.4	910
Sudan	25.2	46.0	46.0	7.8	99.8	252
Ethiopia	49.2	40.0	90.0	20.0	150.0	328
Kenya	24.0	15.0	3.0	4.0	22.0	1090
Tanzania	27.3	34.0	19.0	23.0	76.0	359
Uganda	18.8	31.0	6.0	29.0	66.0	285

*Including the Nile and all other rivers within the state.

competing for a supply of one million cubic meters a year. It is borrowed from Malouf (1991, after Falkenmark).

The table shows that Kenya and Egypt are the countries with the least water resources among the Nile Basin states and would be classified among countries with a "water stress" if we take the scale given by Malouf (1991). However, this stress is in no way comparable to that of other Middle Eastern states such as Palestine (occupied territories), Jordan and Israel where the water competition levels reach the alarming figures of 15,380, 5060 and 2300 respectively (Malouf 1991). All other Nile Basin states have an abundance of water although they may have dry season problems. Taken as a whole the per capita share of the Nile Basin states is 2400 cubic meters. In the Sudan, Uganda and Tanzania the per capita share is 3970, 3500 and 2780 cubic meters respectively while in Kenya and Egypt the per capita share falls to 916 and 1100 cubic meters respectively.

Food production does not depend only on water but also on the available land which can be used for agriculture. Table IX gives the area of these lands in some of the Nile Basin states as well as a land competition index which is the number of people competing for one hectar of agricultural land. A state is considered to be self sufficient in food if the grain sown in one third of its agricultural land can feed its population. The setting aside of one third of the available agricultural land for food growing is reasonable and will not deprive the state from growing other crops that are deemed necessary for its industry or economy. If we assume that the grain production of one third of a hectar of agricultural land is in the range of 1600 kilograms (the average production of one acre of land is two tons) and that the average per capita consumption of grain in one year is about 200 kilograms,(1) then a third of a hectar should feed 8 persons. Therefore, the number of people that are competing for one hectar (land competition index) should not be larger than this figure if the country is to be self sufficient in food.

Table IX clearly shows that all the basin states with the exception of the Sudan, and to a lesser extent Ethiopia, are not self sufficient in food. All import large quantities of grain including the

(1)Historically and until the mid years of the twentieth century the average yearly per capita consumption of grain in Egypt was in the range of 180 kilograms. This amount increased to 240 kilograms in the 1980's.

Table IX: Area of Agricultural land and land competition index in some Nile Basin states

	Population (10^6) 1990	Area of agricultural land (10^6 hectar)			Land competition index (# of people competing for 1 hectar of land)
		Irrigated	rain-fed	Total	
Egypt	52.4	5.1	0.1	5.2	10.1
Sudan	25.2	1.8	5.5	7.3	3.4
Ethiopia	49.2	0.2	6.5	6.7	7.3
Kenya	24.0	0.05	2.4	2.45	10.0
Tanzania	27.3	0.1	3.0	3.1	8.8
Uganda	18.8	—	2.0	2.0	9.4

Sudan and Ethiopia. In 1987 these two countries imported 707,000 and 609,000 tons of grain respectively. In 1991 Ethiopia received more than one million tons. Egypt imports an exceptionally large quantity of grain (amounting to more than 9.3 million tons in 1987); it cultivates grain on only one eighth of its land and the per capita consumption is extremely high, about 18 percent higher than that of the "normal" consumption that we have used in our calculations. It is perhaps significant that famine in the late twentieth century is confined to Africa and to the two countries in the Nile Basin states with the greatest food potential, namely the Sudan and Ethiopia. Although the blame is usually put on droughts, loss of productive cropland due to deforestation, and disruptions caused by civil wars, the International Food Policy Research Institute (1991) cites additional reasons: the prevalence of subsistence-oriented agriculture, inadequate roads and means of transportation and unresponsive governments. An estimated one million people died from famine in Ethiopia in 1983–1986, and more than 500,000 are believed to have died in the Sudan in 1984–1990. Food production in Ethiopia and the Sudan in the late 1980's remained below 1979–1981 levels.

The aforementioned data and discussion show that the water and land resources of the Nile Basin states are unequitably distributed. Taken as a whole the available water resources are ample and can satisfy the needs of all the basin states if they coordinate their efforts and work out a plan that can be beneficial to all. Out of the 476 billion cubic meters of water that these states have access to only 227 billion cubic meters or 36 percent are actually being used. Ethiopia and Uganda alone have 60 percent of the total unused water while Tanzania has close to 18 percent of it. Of all the basin states Egypt stands apart with regard to its water predicament. As a downstream state which depends almost entirely on the Nile for its water, it has to cope not only with the dwindling supplies of a river under stress but also with the increasing demands of the upstream states. For Egypt, the most populous country in the basin, rising demands for food, driven both demographically and by rising standards of living, can only be met with more water which is not only not forthcoming but also not under its control. Egypt's salvation lies in making better use of the water at its disposal and in working out an inter-basin agreement to make sure that its present-day share of the waters of the Nile is accepted by all the other basin states.

The lands that are under cultivation today in the Nile Basin states are in the range of 26.7 million hectars. These represent about 60 percent of the potential land area that could be used for agriculture (about 45 million hectars). The unused land resources are not equally

distributed among the basin states. Egypt and Kenya are the two basin states that are relatively short in water and land and both have to begin schemes for the rational use of their limited resources. All other basin states have unused land resources that can be utilized to secure food. A key factor in obtaining the maximum benefits from these resources is to improve agricultural technology, such as advanced irrigation systems and chemical fertilizers. The International Food Policy Research Institute report (1991) mentions that during the 1984–1985 drought villages taking part in the Marra Rural Development Project in the Sudan produced nearly three times as much grain as other villages.

In addition to the land and water resources of the Nile Basin states, there is the great potential of hydropower generation. We have already touched on part of this potential in our discussion of the Blue Nile. The hydropower potential of the other rivers of the Ethiopian Highlands and of the Equatorial Plateau is equally large if not larger than that of the Blue Nile.

The development of the potential of the Nile Basin states will not take place without problems; foremost among these is the impact that the industrial and agricultural expansion in the upper Nile Basin states would have on the environment and on the quality of the water reaching the downstream states. Egypt, the most industrialized of all the basin states and the country in which land is fully used, suffers from deterioration of the quality of its water; the larger part of its industrial waste as well as agricultural pesticides and fertilizers drain into the Nile. If this pattern of land use occurs in the upstream basin states the result will be devastating to Egypt. So far none of the water agreements contracted among the basin states mentions anything about the quality of water.

The present local and international climate indicates that it will be a long time before the Nile basin states can take matters into their own hands and begin cooperatively to develop their great potential.

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[illegible] development of the potential of the Nil[illegible] [illegible]ons foremost among [illegible] is the impact [illegible] Nile Basin states would have on it [illegible]

[illegible] estimated one million [illegible] the period 1984–1986, and [illegible] 500,000 [illegible] in Ethiopia [illegible] the Sudan in the [illegible] 1979–1981 levels.

The aforementioned data and discussion show that the water and land resources of the Nile Basin states are inequitably distributed. [illegible] as a whole the available water resources [illegible] can satisfy the needs of all the basin states if they coordinate their efforts and set a plan that can be beneficial to all [illegible] billion cubic meters of water the states have access to [illegible] are actually being used [illegible] Uganda alone [illegible] while Tanzania [illegible] which depends almost entirely on the Nile for its water, it is therefore [illegible] with the increasing [illegible] the most populous country in the basin, rising [illegible] standards of living, can only be met [illegible] is not only not forthcoming but also [illegible] control. Egypt's [illegible] an inter-basin [illegible] the waters of the Nile [illegible] accepted by all.

[illegible] situation today in the Nile Basin [illegible]

APPENDIX

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INDEX OF PLACES (COUNTRIES, TOWNS, RIVERS, LAKES & GEOGRAPHIC FEATURES)

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Geology, Hydrology and Utilization

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